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ABSTRACT

This document consists of 11 "NASA Information Summaries" grouped together: (1) "Our Planets at a Glance" (PMS-010); (2) "Space Shuttle Mission Summary: 1985-1986" (PMS-005); (3) "Astronaut Selection and Training" (PMS-019); (4) "Space Station" (PMS-008); (5) "Materials Processing in Space" (PMS-026); (6) "Countdown!: NASA Launch Vehicles and Facilities" (PMS-018); (7) "What's New in NASA Aeronautics" (PMS-027); (8) "The Early Years: Mercury to Apollo-Soyuz" (PMS-001-A); (9) "Space Shuttle Mission Summary: 1981-1983" (PMS-003-A); (10) "Space Shuttle Mission Summary: 1984" (PMS-004-A); and (11) "NASA's Wind Tunnels." (PMS-002). These documents focus on the history, developments, and equipment used in the U.S. space program as well as cooperative efforts with other countries from 1958 until 1988. (CW)

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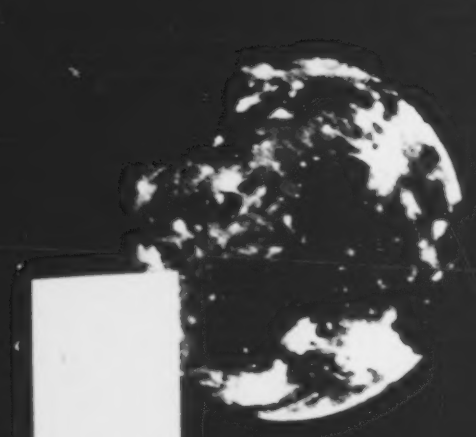
NASA

National Aeronautics and Space Administration

Information Summaries

PMS 010 (KSC)
July 1986

Our Planets At a Glance



Our Planets At a Glance

From our watery world we have gazed upon the cosmic ocean for untold thousands of years. The ancient astronomers observed points of light which appeared to wander among the stars. They called these objects planets, which means wanderers, and named them after great mythological deities—Jupiter, king of the Roman gods; Mars, the Roman god of war; Mercury, messenger of the gods; Venus, the Roman god of love and beauty; and Saturn, father of Jupiter and god of agriculture.

Science flourished during the European Renaissance. Fundamental physical laws governing planetary motion were discovered and the orbits of the planets around the Sun were calculated. In the 17th Century, astronomers pointed a new device called the telescope at the heavens and made startling new discoveries.

But the past 20 years have been the golden age of planetary exploration. Advancements in rocketry during the 1950s enabled mankind's machines to break the grip of Earth's gravity and travel to the Moon and to other planets.

American expeditions have explored the Moon, our robot craft have landed on and reported from the surfaces of Venus and Mars, our spacecraft have orbited and provided much information about Mars and Venus, and have made close range observations while flying past Mercury, Jupiter, Saturn and Uranus.

These voyagers brought a quantum leap in our knowledge and understanding of the solar system. Through the electronic sight and other "senses" of our automated probes, color and complexion have been given to worlds that existed for centuries as fuzzy disks or indistinct points of light.

Future historians will likely view these pioneering flights to the planets as one of the most remarkable human achievements of the 20th Century.

NASA Planetary Exploration

Spacecraft	Mission	Launch Date	Arrival Date	Status
Mariner 2	Venus flyby	8/14/62	12/14/62	Mission complete, craft in solar orbit.
Mariner 4	Mars flyby	11/28/64	7/14/65	Mission complete, craft in solar orbit.
Mariner 5	Venus flyby	6/14/67	10/19/67	Mission complete, craft in solar orbit
Mariner 6	Mars flyby	2/24/69	7/31/69	Mission complete, craft in solar orbit.
Mariner 7	Mars flyby	3/27/69	8/5/69	Mission complete, craft in solar orbit.
Mariner 9	Study Mars from orbit	5/30/71	11/18/71	Mission complete, inoperable remains in Martian orbit.
Pioneer 10	Jupiter flyby	3/2/72	12/3/73	Primary mission complete, craft continues to return heliospheric information enroute toward interstellar space.
Pioneer 11	Jupiter/Saturn flybys	4/5/73	12/2/74 (Jupiter) 9/1/79 (Saturn)	Primary mission complete, continues to return information enroute toward interstellar space.
Mariner 10	Venus/Mercury flybys	11/3/73	2/5/74 (Venus) 3/29/74 (Mercury) 9/21/74 (Mercury) 3/16/75 (Mercury)	Mission complete, craft in solar orbit.
Viking 1	Unmanned landing on Mars	8/20/75	7/19/76 (in orbit) 7/20/76 (lander touchdown)	Mission complete, craft remains on surface and in orbit. Both lander and orbiter have ceased operation.
Viking 2	Unmanned landing on Mars	9/9/75	8/7/76 (in orbit) 9/3/76 (lander touchdown)	Mission complete, craft remains on surface and in orbit. Both lander and orbiter have ceased operation.
Voyager 1	Tour of Jupiter	9/5/77	3/5/79 (Jupiter) 11/12/80 (Saturn)	Primary mission complete. Craft continues to return heliospheric information enroute toward interstellar space.
Voyager 2	Tour of the outer planets	8/20/77	7/9/79 (Jupiter) 8/25/81 (Saturn) 1/24/86 (Uranus) 1989 (Neptune)	Mission continues. Craft has surveyed three of four planetary targets. On way to Neptune.
Pioneer Venus 1	Orbital studies of Venus	5/20/78	12/4/78	Orbiter continues to return images and data.
Pioneer Venus 2		8/8/78	12/9/78	Mission complete. Probes impacted on surface.

Interplanetary Spacecraft

NASA's space probes to the planets have come in many shapes and sizes. While they are designed to fulfill separate and specific mission objectives, the craft share much in common.

Each space probe has consisted of various scientific instruments selected for the mission, supported by basic subsystems for electrical power, trajectory and orientation control, and for processing data and communicating with Earth.

Electrical power is required to operate the spacecraft instruments and systems. NASA has used both solar energy from arrays of photovoltaic cells and small nuclear generators as power plants on its interplanetary probes. Rechargeable batteries are employed for backup and supplemental power.

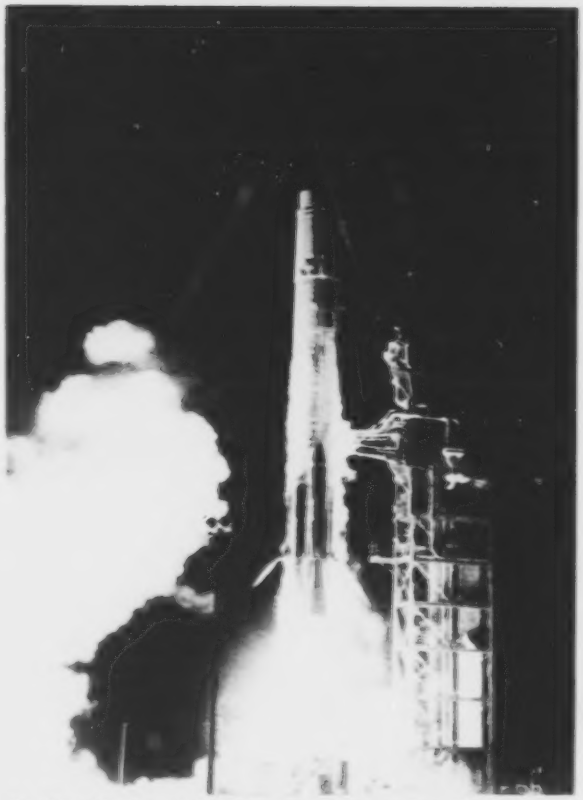
Imagine that a craft has successfully journeyed millions of miles through space to fly only once near a planet, and its cameras and other sensing instruments are pointed the wrong way as it zooms past the target! To help prevent this from happening, a subsystem of small thrusters is used to control interplanetary spacecraft. The thrusters are linked with devices which maintain a fix on selected stars. Just as the Earth's early seafarers used the stars to navigate the oceans, spacecraft use stars to keep their bearings in space. With the subsystem locked onto "fixed" points of reference, flight controllers can keep scientific instruments pointed at the target body and a spacecraft's communications antennas pointed toward Earth.

To ensure that a space probe encounters a planet at the planned distance and on the proper trajectory, another major subsystem makes course corrections after the spacecraft is enroute.

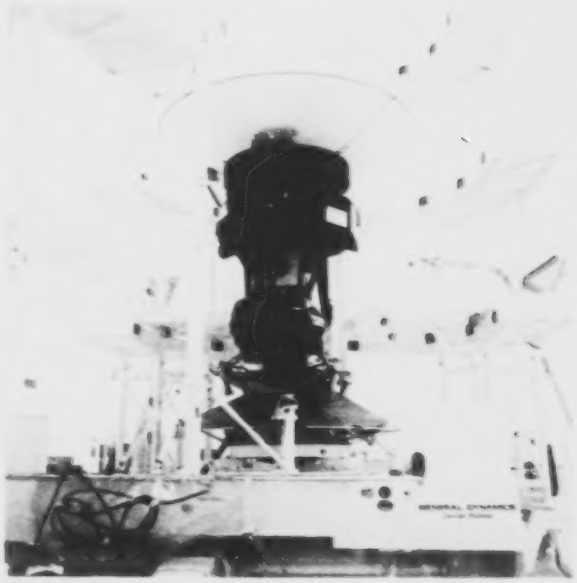
During the first decade of planetary flights, NASA spacecraft were dispatched to scan the other inner planets—Mercury, Venus, and Mars. These worlds, and our own, are known as the terrestrial planets because of their similarity to Earth's rocky composition.

For these early reconnaissance missions, NASA employed a highly successful series of spacecraft called Mariners. Their flights helped shape the planning of later missions. Between 1962 and 1973, seven Mariner missions were successful. Three Mariner attempts—the first, third and eighth—failed

All of the Mariner spacecraft used solar panels as their primary power source. The first and the final versions of the spacecraft had two wings covered with photovoltaic cells. Other Mariner space probes were equipped with four solar panels extending from their octagonal bodies. Spacecraft in the series ranged from under 500 pounds (Mariner 2 Venus probe) to more than 2,000 pounds (Mariner 9 orbiter). Their basic



An Atlas Centaur rocket lifts away from its Cape Canaveral launch pad carrying the Mariner 6 space probe.



The Voyager 1 probe to the outer planets awaits final launch preparations at Kennedy Space Center.

design, however, remained quite similar throughout the program. The Mariner 5 Venus probe, for example, had originally been a backup spacecraft for the Mariner 4 Mars flyby. The Mariner 10 spacecraft sent to Venus and Mercury used components left over from the Mariner 9 Mars orbiter program

In 1972, NASA opened the second decade of planetary exploration with the launch of a Jupiter probe. Interest was shifting to the outer planets, giant balls of dense gas quite different from the terrestrial worlds we had surveyed.

Four spacecraft—two Pioneers and two Voyagers—were sent to tour the outer regions of our solar system. They will eventually become the first human artifacts to travel to distant stars.

Because they are traveling even farther from the Sun, the outer planet probes operate on nuclear-generated electric power.

While probing new territory beyond the asteroid belt, NASA developed highly specialized space craft to revisit our neighbors Mars and Venus. Twin Viking landers evolved from the lunar Surveyor program. The Mars landers were equipped to serve as biology laboratories, seismic and weather stations. Two advanced orbiters—descendents of the Mariner craft—were sent to study Martian features from above.

The Pioneer Venus orbiter, a drum-shaped spacecraft, was equipped with a radar instrument that "sees" through the planet's dense cloud cover to study surface features. A separate spacecraft called the Pioneer Venus multiprobe carried four instrumented probes which were dropped to the planet's surface. The probes, and the instrumented main body, radioed information about the planet's atmosphere before falling victim to its extremely high pressures and temperatures.

Comparing the Planets

Despite their efforts to peer across the vast distances of space through an obscuring atmosphere, scientists of the past had only one planet they could study closely, the Earth. But the past 20 years of planetary spaceflight have given new definitions to "Earth" sciences like geology and meteorology and spawned an entirely new discipline called comparative planetology.

By studying the geology of planets and moons, and comparing the differences and similarities between them, we are learning more about the origin and history of these worlds and the solar system as a whole.

Weather affects all of us on the Earth. In its extremes, weather can threaten life, and long term climatic changes on the Earth could be catastrophic. It is important to understand our complex weather machine. But other planets have weather too. By studying the weather on other worlds and comparing it to our own, we may better understand our Earth.

Geology and weather are just two major areas of science benefitting from our planetary space probes. Someday perhaps, terrestrial biologists will get their chance to compare the only lifeforms we've ever known, those on our Earth, to living creatures from another world.

The Moon-like surface of Mercury is revealed in this photograph taken by the approaching Mariner 10 spacecraft.

Mercury

Obtaining the first closeup views of Mercury was the primary objective of the Mariner 10 space probe, launched from Kennedy Space Center in November 1973. After a journey of nearly five months, which included a flyby of Venus, the spacecraft passed within 805 kilometers (500 miles) of the solar system's innermost planet on March 29, 1974.

The photographs Mariner 10 radioed back to Earth revealed an ancient, heavily cratered surface

on Mercury, closely resembling our own Moon. The pictures also showed huge cliffs crisscrossing the planet. These apparently were created when Mercury's interior cooled and shrank, compressing the planet's crust. The cliffs are as high as two kilometers (1.2 miles) and as long as 1500 kilometers (932 miles).

Instruments onboard Mariner 10 discovered that the planet has a weak magnetic field and a trace of atmosphere—a trillionth the density of the Earth's and composed chiefly of argon, neon and helium. The spacecraft reported temperatures ranging from 510 degrees Celsius (950 degrees Fahrenheit) on Mercury's sunlit side to – 210 degrees Celsius (– 346 degrees Fahrenheit) on the dark side. Mercury literally bakes in daylight and freezes at night.

The days and nights are long on Mercury. It takes 59 Earth days for Mercury to make a single rotation. It spins at a rate of about 10 kilometers (about 6 miles) per hour, measured at the equator, as compared to Earth's spin rate of about 1600 kilometers (about 1,000 miles) per hour at the equator.

Mercury, like the Earth, appears to have a crust of light silicate rock. Scientists believe it has a heavy iron-rich core that makes up about half of its volume.

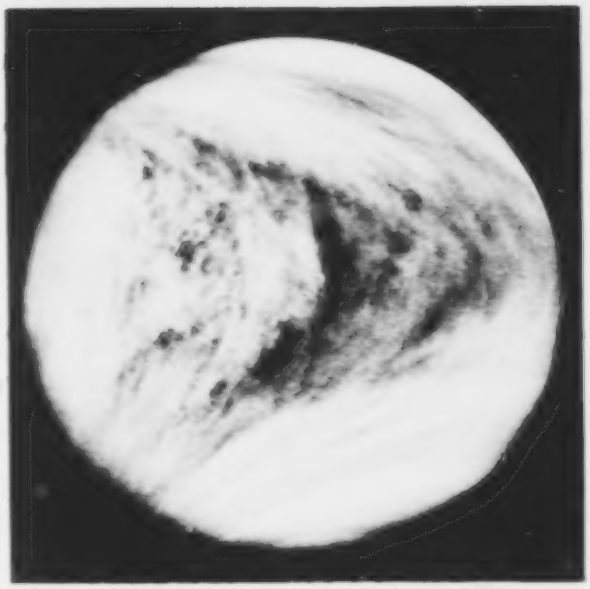
Mariner 10 made two additional flybys of Mercury—on September 21, 1974 and March 16, 1975—before control gas used to orient the spacecraft was exhausted and the mission was concluded.

Until the Mariner 10 probe, little was known about Mercury. Even the best telescopic views from Earth showed Mercury as an indistinct object lacking any surface detail. The planet is so close to the Sun that it is usually lost in the Sun's glare. When it is visible on Earth's horizon just after sunset or before dawn, it is obscured by the haze and dust in our atmosphere. Only radar telescopes gave any hint of Mercury's surface conditions prior to the voyage of Mariner 10.

Venus

Veiled by dense cloud cover, our nearest neighboring planet was the earliest subject of interplanetary explorations. The Mariner 2 space probe, launched August 27, 1962, was the first of more than a dozen successful American and Soviet missions to study the mysterious planet. As spacecraft zoomed by, plunged into the atmosphere, and gently landed on Venus, romantic myths and speculations about our twin planet were laid to rest.

Mariner 2 passed within 34,762 kilometers (21,600 miles) of Venus on December 14, 1962, and became the first spacecraft to scan another planet. Its instruments made measurements of Venus for 42 minutes. Mariner 5, launched in June 1967, flew much closer to the planet. Passing within 4,023 kilometers (2,500 miles) of Venus on the second U.S. flyby, its instruments measured the planet's magnetic field, ionosphere, radiation belts and temperatures. On its way to Mercury, Mariner 10 flew by Venus and returned ultraviolet pictures showing cloud circulation patterns in the Venusian atmosphere.



An enhanced photo taken by the Pioneer Venus Orbiter shows the circulation of the dense Venusian atmosphere.

In the spring and summer of 1978, two spacecraft were launched to unravel the mystery of Venus. On December 4, the Pioneer Venus Orbiter became the first spacecraft placed in orbit around the planet.

Five days later, the five separate components which had made up the second spacecraft—the Pioneer Venus Multiprobe—entered the Venusian atmosphere at different locations above the planet. Four independent probes and a main body radioed data about the planet's atmosphere back to Earth during their descent toward the surface.

Venus more nearly resembles Earth in size, physical composition, and density than any other known planet. However, spacecraft have discovered vast differences in how these planets have evolved.

Approximately 97 percent of Venus' atmosphere, about a hundred times as dense as Earth's, is carbon dioxide. The principal constituent of Earth's atmosphere is nitrogen. Venus' atmosphere acts like a greenhouse, permitting solar radiation to reach the surface but trapping the heat which would ordinarily be radiated back into space. As a result, surface temperatures are 482 degrees Celsius (900 degrees Fahrenheit), hot enough to melt lead.

Radar aboard the Pioneer Venus orbiter provided a means of seeing through Venus' dense

The solar system's only known oasis of life, our planet Earth, is photographed by the Apollo 17 astronauts.

Apollo 15 Astronaut David Scott explores the lunar surface about 16 kilometers (ten miles) east from the base of the Apennine Mountains visible in the background.

cloud cover and determining surface features over much of the planet. Among the features determined are two continent-like highland areas. One, about half the size of Africa, is located in the equatorial region. The other, about the size of Australia, is to the north.

There is evidence of two major active volcanic areas, one larger than Earth's Hawaii-Midway volcanic chain (Earth's largest)—with a mountain higher than Everest (Earth's highest mountain). The concentration of lightning over these two regions suggests frequent volcanic activity at both places. Discovery of active volcanism on Venus makes it the third solar system body known to be volcanically active. The others are Earth and the Jovian satellite Io.

Venus' predominant weather pattern is a high speed circulation of Venus' clouds which are made up of sulphuric acid. These speeds reach as high as 362 kilometers (225 miles) per hour. The circulation is in the same direction—east to west—as Venus' slow retrograde rotation. Earth's winds blow from west to east, the same direction as its rotation.

NASA's Pioneer-Venus orbiter continues to circle the planet. It is expected to send data about Venus to Earth for years to come.

Earth

From our journeys into space, we have learned much about our home planet—Earth. The first American satellite, Explorer 1, was launched from Cape Canaveral on January 31, 1958. It discovered an intense radiation zone, now called the Van Allen Radiation Region, surrounding Earth. Since then, other research satellites have revealed that our planet's magnetic field is distorted into a teardrop shape by the solar wind—the stream of charged particles continuously ejected from the Sun. We've learned that Earth's magnetic field does not fade off into space but has definite boundaries. And we now know that our wispy upper atmosphere, once believed calm and quiescent, seethes with activity, swelling by day and contracting by night. It is affected by the changes in solar activity and contributes to weather and climate on Earth.

Satellites positioned about 35,000 kilometers (22,000 miles) out in space play a major role every day in local weather forecasting. Their watchful electronic eyes warn us of dangerous storms. Continuous global monitoring provides a vast amount of useful data, as well as contributing to a better understanding of Earth's complex weather machine.

From their unique vantage point in space, spacecraft can survey the Earth's resources and monitor the planet's health.

As viewed from space, Earth's distinguishing characteristics are its blue waters and white clouds. Enveloped by an ocean of air consisting of 78 percent nitrogen and 21 percent oxygen, the planet is the only one in our solar system known to harbor life. Circling the Sun at an average distance of 149 million kilometers (93 million miles), Earth is the third planet from the Sun and the fifth largest in the solar system.

Its rapid spin and molten nickel-iron core give rise to an extensive magnetic field, which, coupled with the atmosphere, shields us from nearly all of the harmful radiation coming from the Sun and other stars. Most meteors burn up in Earth's atmosphere before they can strike the surface. The planet's active geological processes have left no evidence of the ancient pelting it almost certainly received soon after it formed.

The Earth has a single natural satellite—the Moon.

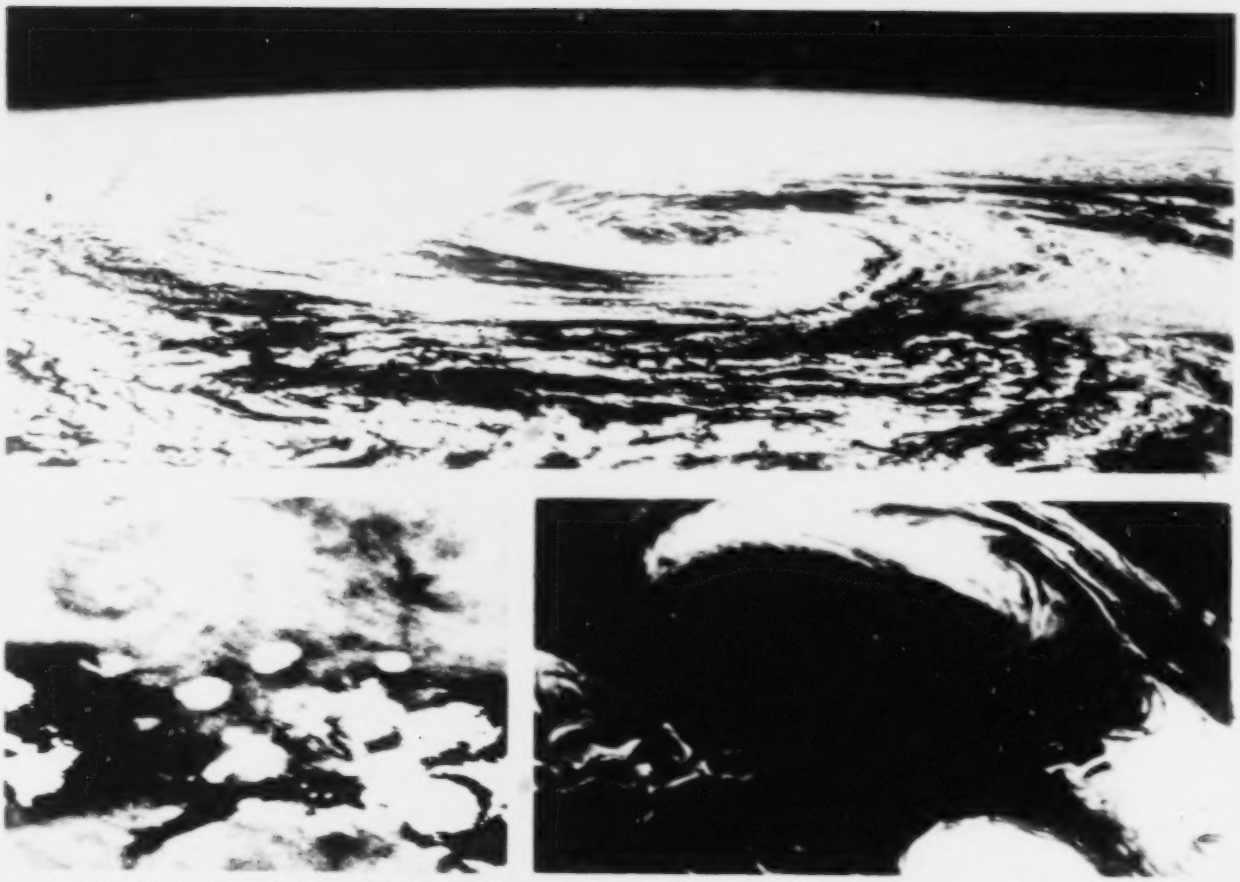
Moon

The first human footsteps upon an alien world were made by American astronauts on the dusty surface of our airless, lifeless companion. Before the manned Apollo expeditions, the Moon was studied by the unmanned Ranger, Surveyor, and Lunar Orbiter spacecraft.

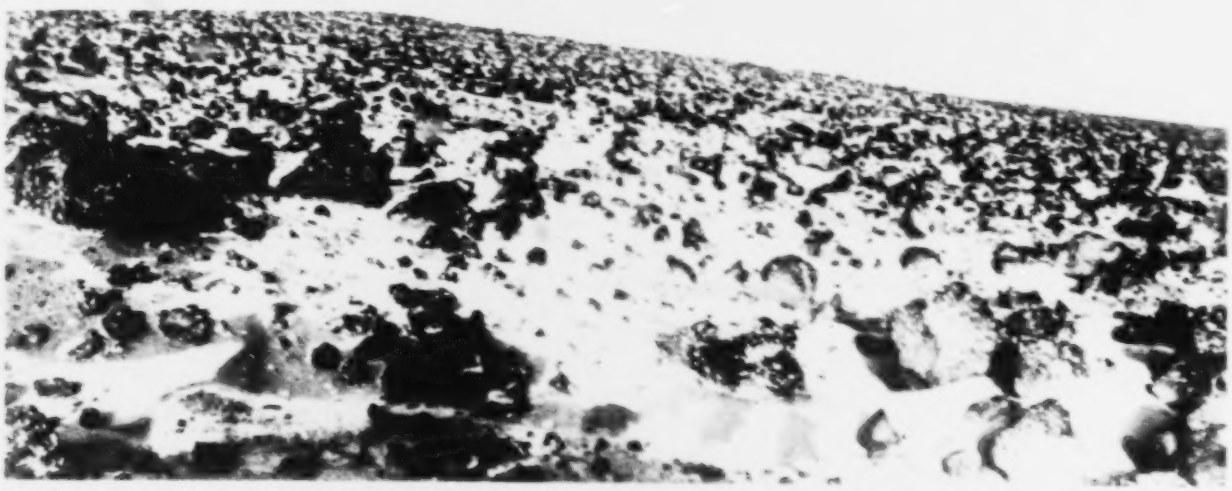
The Apollo program left us a large legacy of lunar materials and data. Six two-man crews landed on and explored the lunar surface between 1969 and 1972. They returned a collection of rocks and soil weighing 382 kilograms (842 pounds) and consisting of more than 2,000 separate samples.

From this material and other studies, scientists have constructed a history of the Moon dating back to its infancy. Rocks collected from the lunar highlands date about 4.0 to 4.3 billion years old. It's believed that the solar system formed about 4.6 billion years ago. The first few million years of the Moon's existence were so violent that few traces of this period remain. As a molten outer layer gradually cooled and a solidified into different kinds of rock, the Moon was bombarded by huge asteroids and smaller objects. Some of the asteroids were the size of small states, like Rhode Island or Delaware, and their collisions with the Moon created huge basins hundreds of kilometers across.

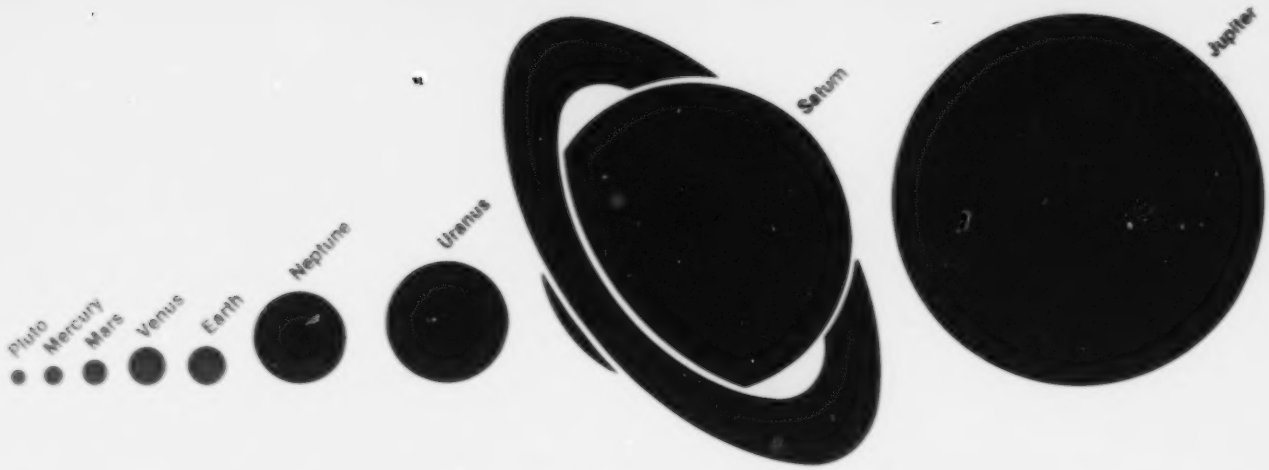
The catastrophic bombardment died away about 4 billion years ago, leaving the lunar highlands covered with huge overlapping craters and a deep layer of shattered and broken rock. Heat produced by the decay of radioactive elements began to melt the inside of the Moon at depths of about 200 kilometers (124 miles) below its surface. Then, from about 3.8 to 3.1 billion years ago, great floods of lava rose from inside the Moon and



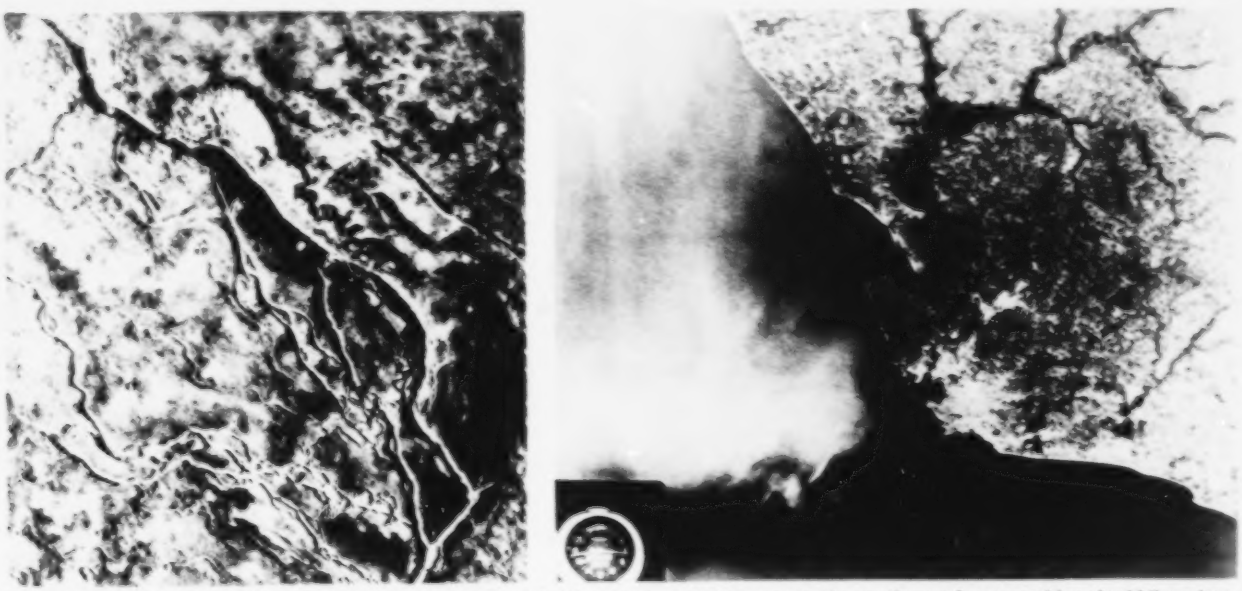
Hurricanes and typhoons on Earth are powered by differences in atmospheric temperatures and density. We know that similar weather conditions occur on Mars and Jupiter. Compare the sprawling Pacific storm (top) photographed by the Apollo 9 astronauts with a Martian cyclone (lower left) and Jupiter's Great Red Spot (lower right). The Martian cyclone is about 250 kilometers (155 miles) in diameter. The Great Red Spot on Jupiter is a hurricane-like feature which has raged for centuries. This single Jovian storm system is several times larger than the Earth.



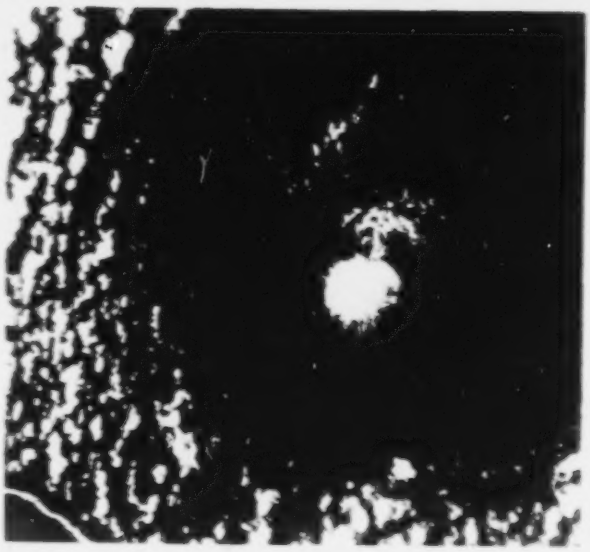
Jack Frost lives on Mars too. Light patches of frost on the Plains of Utopia (above) were observed during the Martian winter. The Viking landers became our first weather stations on another planet and scientists on Earth continue to get weekly updates from the Viking 1 site. Had Viking 1's first weather report been aired on the 6 p.m. news, it would have gone something like this: "Light winds from the east in the late afternoon, changing to light winds from the southeast after midnight. Maximum winds were 15 miles per hour. Temperatures ranged from minus 122 degrees Fahrenheit just after dawn to minus 22 degrees in midafternoon. Atmospheric pressure 7.70 milibars." (On Earth that same day, the lowest recorded temperature was minus 100 degrees Fahrenheit at the Soviet Vostok Research Station in the Antarctic.)

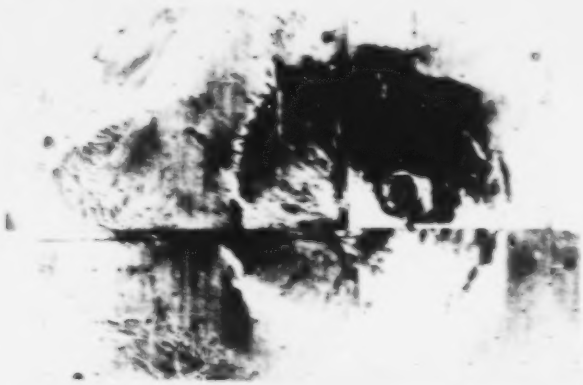


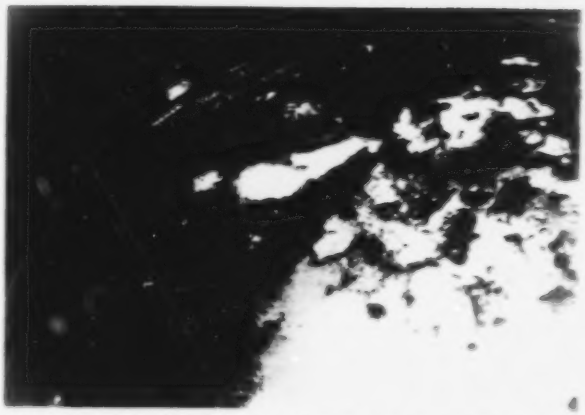
	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean Distance From Sun (Millions of Kilometers)	57.9	108.2	149.6	227.9	778.3	1,427	2,870	4,497	5,900
Period of Revolution	88 days	224.7 days	365 days	687 days	11.86 years	29.46 years	84 years	165 years	248 years
Rotation Period	59 days	243 days Retrograde	23 hours 56 minutes	24 hours 37 minutes	9 hours 55 minutes	10 hours 40 minutes	17.2 hours Retrograde	18 hours 30 min. (?)	6 days 9 hours 18 minutes Retrograde
Inclination of Axis	Near 0°	3°	23°27'	25°12'	3°5	26°44	97°55	28°48	?
Inclination of Orbit to Ecliptic	7°	3.4°	0°	1.9°	1.3°	2.5°	0.8°	1.8°	17.2°
Eccentricity of Orbit	.206	.007	.017	.093	.048	.056	.047	.009	.254
Equatorial Diameter (Kilometers)	4,880	12,100	12,756	6,794	143,200	120,000	51,800	49,500 (?)	3,000 (?)
Atmosphere (Main Components)	Surface's None	Carbon Dioxide	Nitrogen Oxygen	Carbon Dioxide	Hydrogen Helium	Hydrogen Helium	Helium Hydrogen Methane	Hydrogen Helium Methane	None Detected
Satellites Rings	0 0	0 0	1 0	2 0	16 1	21 1,000 (?)	15 11 (?)	2 ?	1 ?



Large Martian channels (left) start near the volcano Elysium Mons and wind their way to the northwest for several hundred kilometers. Their origin is controversial. Did they form from lava flows or water released from the melting of ground ice during volcanic eruptions? Compare the Martian channels with the Skylab photograph of the Rio de la Plata river in Uruguay (right).

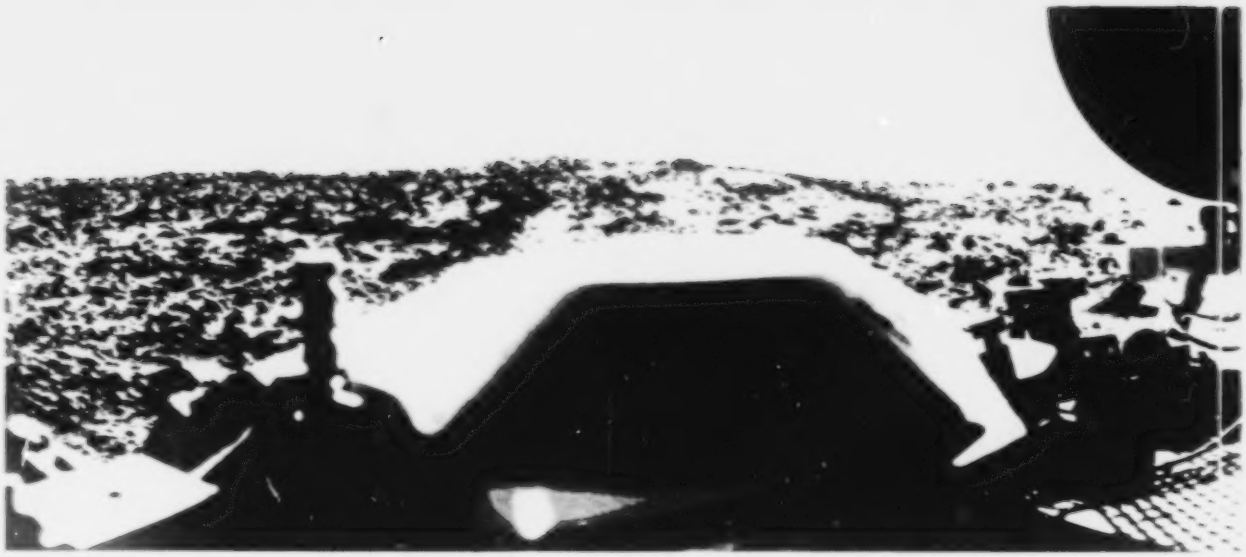






Impact craters are formed when a planetary surface is struck by a meteorite. Mercury, our Moon, and many of the icy, rocky satellites of the outer solar system are characterized by heavily cratered surfaces. On Earth, geological processes tend to destroy evidence of ancient crater impacts, although some more recent craters remain discernable. Compare the lunar craters (top) with craters on Mars (bottom).

Volcanoes are vents in a planet's crust that permit the escape of internal heat. The geologically active Earth has hundreds of volcanoes, like this one in New Zealand (top). Compare it to one of the large shield-type volcanoes on Mars (center). It was a surprise to scientists that Jupiter's moon Io is volcanically active (bottom). Voyager 1 photographed a volcanic plume (visible above the limb of Io) about 11 hours before its closest approach. Researchers believe tidal forces resulting from Jupiter's massive size are responsible for the internal heating of Io. The active volcanoes on Io are the only ones known in the solar system other than Earth's. In addition to Mars, evidence of volcanic activity in the past has been found on the Moon, Mercury and Venus.



A rock-littered, rolling landscape is seen by the Viking 1 lander after its touchdown on Mars. Parts of the spacecraft are visible in the foreground. This is a portion of the first panoramic view returned to Earth by the robot spacecraft.

poured out over its surface, filling in the large impact basins to form the dark parts of the Moon—called maria or seas. Explorations show that there has been no significant volcanic activity on the Moon for more than 3 billion years and, since then, the lunar surface has been altered only by the rare impacts of large meteorites and by the atomic particles from the Sun and stars.

If our astronauts had landed on the Moon a billion years ago, it would have looked very much as it does today, and thousands of years from now, the footsteps left by the Apollo crews will remain sharp and clear.

One question about the Moon that remains unsolved is, where did it come from? Three theories attempt to explain its existence: that it formed near the Earth as a separate body, that it separated from the Earth, or that it formed somewhere else and was captured by the Earth. The notion that the Moon may have once been part of the Earth now appears less likely than the other suggestions because of the difference between the two bodies in chemical composition, such as the absence of water either free or chemically combined in rocks. The other two theories are about evenly matched in strengths and weaknesses. The origin of the Moon remains a mystery.

Mars

Of all the planets, Mars has long been considered the solar system's prime candidate for harboring extraterrestrial life. Astronomers observing the red planet through telescopes saw what appeared to be straight lines crisscrossing its surface. These observations—later determined to be optical illusions—led to the popular notion that intelligent beings had constructed a system of irrigation canals on the planet. In 1938, when Orson Welles broadcast a radio drama based on the science fiction classic "War of the Worlds," enough people believed in the tale of invading Martians to cause a near panic.

Another reason for scientists to expect life on Mars arose from apparent seasonal color changes on the planet's surface. That led to speculation that conditions might support a bloom of Martian vegetation during the warmer months and cause plant life to become dormant during colder periods.

In August and September 1975, two Viking spacecraft—each consisting of an orbiter and a lander—were launched from Kennedy Space Center, Florida on a mission designed to answer several questions, including: is there life on Mars? Nobody expected the spacecraft to spot Martian cities but it was hoped the biology experiments on board the landers would at least find evidence of primitive life, past or present.

The results sent back by the two unmanned laboratories, which soft-landed on the planet, were teasingly inconclusive. We still don't know whether life exists on Mars. Small samples of the red Martian soil were specially treated in three different experiments designed to detect biological processes. While some of the tests indicated biological activities were occurring, the same results could be explained by the planet's soil chemistry. There was a notable absence of evidence that organic molecules exist on Mars.

Despite the inconclusive results of the biology experiments, we know more about Mars than any other planet except Earth. Six U.S. missions to the red planet have been carried out. Four Mariner spacecraft—three which flew by the planet and

one which was placed into Martian orbit—surveyed the planet extensively before the Viking missions.

Mariner 4, launched in late 1964, flew past the planet on July 14, 1965. It approached to within 9,656 kilometers (6,000 miles) of the surface. Returning 22 close-up pictures of Mars, it found no evidence of artificial canals or flowing water. Mariners 6 and 7 followed during the summer of 1969, returning about 200 pictures showing a diversity of surface conditions during their flybys. Earlier atmospheric data were confirmed and refined. On May 30, 1971, Mariner 9 was launched on a mission to study the Martian surface from orbit for nearly a year. It arrived five and a half months after liftoff, only to find Mars in the midst of a planet-wide dust storm which made surface photography impossible for several weeks. But after the storm cleared, Mariner 9 began returning the first of 7,000 pictures which revealed previously unknown Martian features, including evidence that rivers, and possibly seas, could have once existed on the planet. The Mariner missions to Mars were followed up with the Viking Project—the first American soft landing on the surface of another planet, excluding our own Moon.

All four spacecraft, two orbiters and two landers, exceeded by large margins their design lifetime of 90 days. The four spacecraft were launched in 1975 and began Mars operation in 1976. The first to fail was Orbiter 2 which stopped operating in July 24, 1978 when its attitude control gas was depleted because of a leak. Lander 2 operated until April 12, 1980 when it was shut down due to battery degeneration. Orbiter 1 operated until August 7, 1980, when it too used the last of its attitude control gas. Lander 1 ceased operating on November 13, 1983.

Photos sent from the Plain of Chryse—where Viking 1 landed on July 20, 1976—show a bleak, rusty red landscape. A panorama returned by the robot explorer pictures a gently rolling plain, littered with rocks and graced by rippled sand dunes. Fine red dust from the Martian soil gives the sky a pinkish hue. Viking 2 landed on the Plain of Utopia, arriving several weeks after its twin. The landscape it viewed is more rolling than that seen by Viking 1, and there are no dunes visible.

Both Viking landers became weather stations, recording wind velocity and direction, temperatures and atmospheric pressure.

The four largest Martian volcanoes stand out as distinctive dark circular features in this photograph taken from a distance of 575,000 kilometers (350,000 miles) by the approaching Viking 1 spacecraft.

As days became weeks, the Martian weather changed little. The highest atmospheric temperature recorded by either lander was – 21 degrees Centigrade (– 17 degrees Fahrenheit) at the Viking 1 site in midsummer.

The lowest temperature, – 124 degrees Celsius (– 191 degrees Fahrenheit), was recorded at the more northerly Viking 2 site during winter. Wind speeds near hurricane force were measured at the two Martian weather stations during global dust storms. Viking 2 photographed light patches of frost—probably water ice—during its second winter on the planet.

The Martian atmosphere, like that of Venus, is primarily carbon dioxide. Present in small percentages are nitrogen, oxygen and argon, with trace amounts of krypton and xenon. Martian air contains only about 1/1000 as much water as Earth's

but even this small amount can condense out and form clouds which ride high in the atmosphere, or swirl around the slopes of towering Martian volcanoes. Local patches of early morning fog can form in valleys.

There is evidence that in the past, a denser Martian atmosphere may have allowed water to flow on the planet. Physical features closely resembling shorelines, gorges, riverbeds and islands suggest that great rivers once existed on the planet.

Mars has two small, irregularly shaped moons, Phobos and Deimos, with ancient, cratered surfaces.

Jupiter

Outward from Mars and beyond the Asteroid Belt lie the giants of our solar system.

In March 1972, NASA dispatched the first of four space probes to survey the colossal worlds of gas and their moons of rock and ice. For each probe, Jupiter was the first port of call.

Pioneer 10, which lifted off from Kennedy Space Center March 2, 1972, was the first spacecraft to penetrate the Asteroid Belt and travel to the outer regions of the solar system. In December 1973, it returned the first closeup pictures of Jupiter as it flew within 132,252 kilometers (81,168 miles) of the planet's banded cloudtops. Pioneer 11 followed a year later. Voyagers 1 and 2 were launched in the summer of 1977 and returned spectacular photographs of Jupiter and its 16 satellites during flybys in 1979.

During their visits these exploring spacecraft found Jupiter to be a whirling ball of liquid hydrogen, topped with a uniquely colorful atmosphere which is mostly hydrogen and helium. It contains small amounts of methane, ammonia, ethane, acetylene, phosphene, germanium tetrahydride and possibly hydrogen cyanide. Jupiter's clouds also contain ammonia and water crystals. Scientists believe it likely that between the planet's frigid cloud tops and the warmer hydrogen ocean that lies below, there are regions where methane, ammonia, water and other gases could react to form organic molecules. Because of Jupiter's atmospheric dynamics, however, these organic compounds, if they exist, are probably short lived.

The Great Red Spot has been observed for centuries through Earth-based telescopes. It is a tremendous atmospheric storm, similar to Earth's hurricanes, which rotates counterclockwise.

Our space probes detected lightning in Jupiter's upper atmosphere and observed auroral emissions

Jupiter looms ahead of the Voyager 1 spacecraft. The Great Red Spot is visible at the lower left. Slightly above the feature, and to the right, is the volcanically active moon Io.

similar to Earth's northern lights in the Jovian polar regions.

Voyager 1 returned the first evidence of a ring encircling Jupiter. Photographs returned by the spacecraft and its companion Voyager 2 showed a narrow ring too faint to be seen by Earth's telescopes.

Largest of the solar system's planets, Jupiter rotates at a dizzying pace—once every 9 hours, 55 minutes and 30 seconds. It takes the massive planet almost 12 Earth years to complete a journey around the Sun. The planet is something of a mini solar system, with 16 known moons orbiting above its clouds.

A new mission to Jupiter—the Galileo Project—is being readied for the late 1980s. An atmospheric probe will descend into Jupiter's cloud layers while another spacecraft orbits the planet.

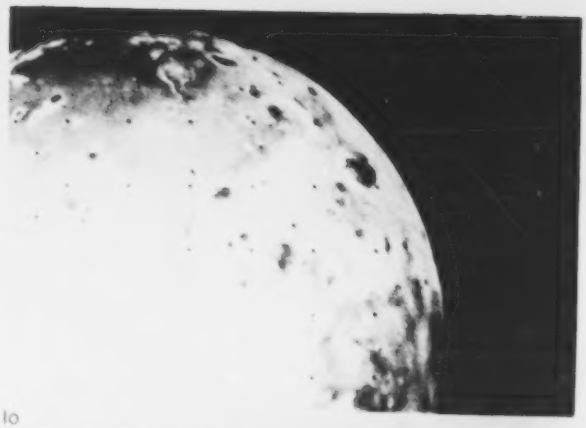
Galilean Satellites

In 1610, Galileo Galilei aimed his telescope at Jupiter and spotted four points of light orbiting the planet. For the first time, humans had seen the moons of another planet. The four worlds would become known as Galilean satellites, in honor of their discoverer. But Galileo might happily have traded his moment in history for a look at the dazzling photographs returned by the Voyager spacecraft as they flew past Jupiter's four planet-sized satellites.

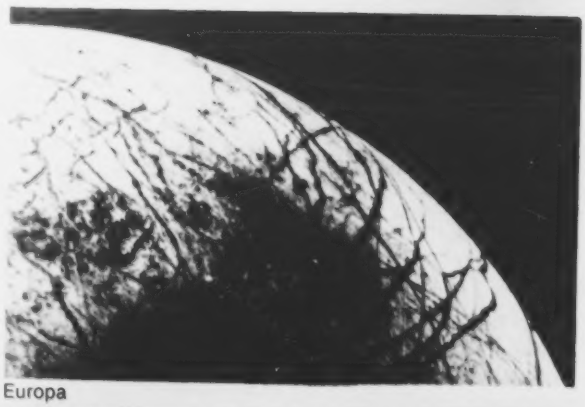
One of the most remarkable findings of the Voyager mission was the discovery of active volcanoes on the Galilean moon Io. It was the first time volcanic eruptions were observed on a world other than Earth. The Voyager cameras identified at least eight active volcanoes on the moon. Plumes extended as far as 250 kilometers (155 miles) above the moon's surface. The satellite's pizza-colored surface, rich in hues of oranges and yellow, is probably the result of sulphur-rich materials which have been brought to the surface by volcanic activity.

Europa, approximately the same size as our Moon, is the brightest Galilean satellite. Its surface displays a complex array of streaks that indicate the crust has been fractured.

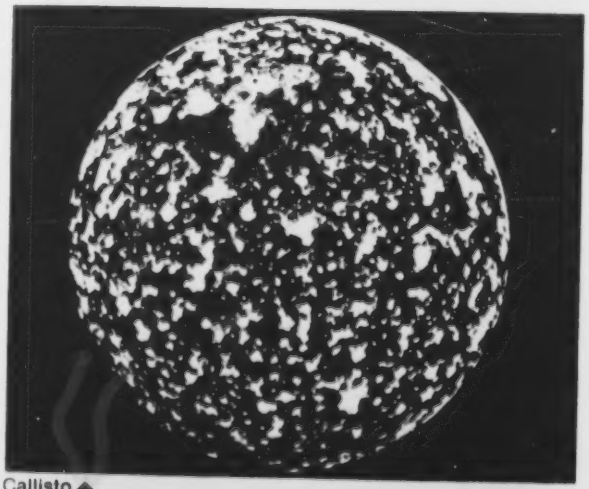
Like Europa, the other two Galilean moons—Ganymede and Callisto—are frozen worlds of ice and rock. Ganymede is the largest satellite in the solar system—larger than the planet Mercury. It is composed of about 50 percent water or ice and the rest rock. Callisto, only slightly smaller than Ganymede, has the lowest density of any Galilean satellite, implying that it has large amounts of water in its composition. More detailed studies of the Galilean satellites will be performed by the next orbiting spacecraft scheduled to be sent to Jupiter.



Io

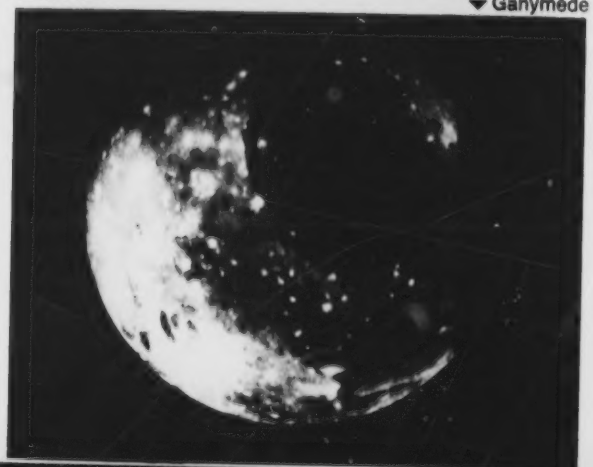


Europa



Callisto ▲

▼ Ganymede



Saturn

No planet in the solar system is adorned like Saturn. Its exquisite ring system is unrivalled. Like Jupiter, Saturn is composed mostly of hydrogen. But in contrast to the vivid colors and wild turbulence found in Jupiter's clouds, Saturn has a more subtle, butterscotch hue and its markings are often muted by high altitude haze.

Three American spacecraft have visited Saturn. Pioneer 11 zipped by the planet and its moon Titan in 1979, returning the first closeup pictures. Voyager 1 followed in November 1980, sending back breathtaking photographs that revealed for the first time the complexities of Saturn's ring system and moons. Voyager 2 flew by the planet and its moons in August 1981.

The spacecraft discovered that there are actually thousands of ringlets encircling Saturn.

Saturn's rings are composed of countless low-density particles orbiting individually around the equator at progressive distances from the planet's cloud tops. Analysis of radio waves passing through the rings showed that the particles vary widely in size, ranging from dust to boulders. Most of the material is ice and frosted rock.

Scientists believe the rings resulted, either from a moon or a passing body which ventured too close to Saturn and was torn apart by great tidal forces, or the incomplete coalescence of primordial planetary material, or from collisions with larger objects orbiting the planet.

Unable either to form into a moon or to drift away from each other, individual ring particles appear to be held in place by the gravitational pulls of Saturn and its satellites.

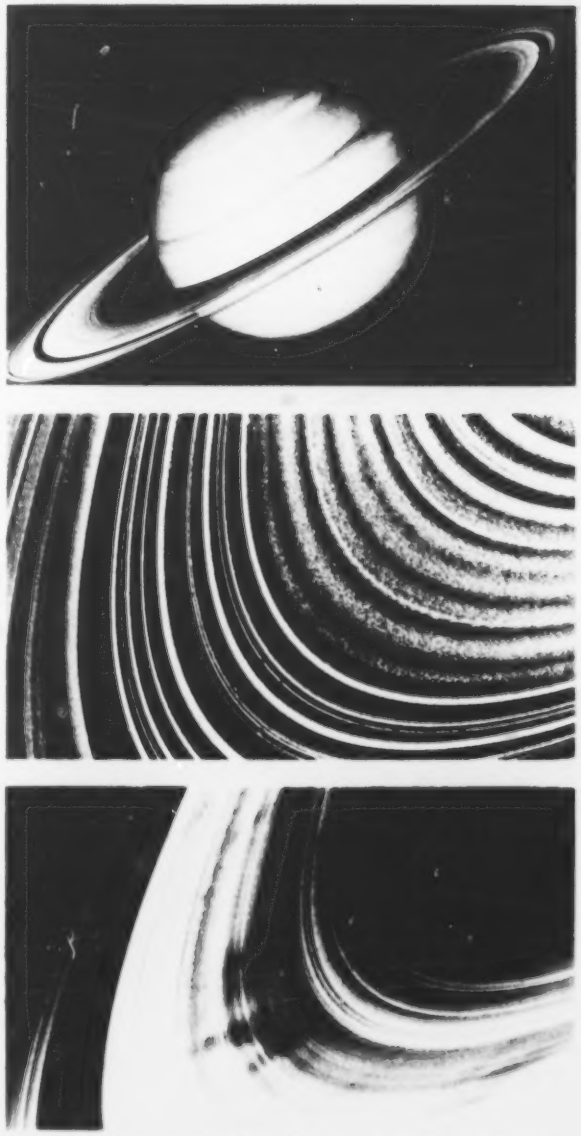
Radio emissions quite similar to the static heard on an AM car radio during an electrical storm were detected by the Voyager spacecraft. These emissions are typical of lightning but are believed to be coming from the planet's ring system rather than its atmosphere. No lightning was observed in Saturn's atmosphere. But as they had at Jupiter, the Voyager spacecraft saw a version of Earth's northern and southern lights near Saturn's poles.

The probes also studied Saturn's moons, detected undiscovered moons, found some that share the same orbit, and determined that Titan has a nitrogen-based atmosphere.

A large constituent of Titan's atmosphere is methane. The surface temperature of Titan appears to be around the "triple" point of methane, meaning methane may be present on Titan in all three states: liquid, gaseous, and solid (ice). Methane, therefore, may play the same role on Titan that water plays on Earth.

Although the spacecraft's cameras could not peer through the dense haze that obscures the surface of Titan, measurements indicate Titan may be a place where rain or snow falls from methane clouds and rivers of methane cut through methane glaciers.

Continuing photochemistry due to solar radiation may be converting Titan's methane to ethane, acetylene, ethylene, and, in combination with nitrogen, hydrogen cyanide. The latter is a building block to amino acids. Titan's temperature is believed to be too low to permit progress beyond this stage of organic chemistry. However, this condition may be similar to that which occurred in the atmosphere of the primeval Earth between three and four billion years ago.



Voyager 2 photographs of the Saturn ring system during its August 1981 approach. The shadow of the planet's exquisite ring system can be clearly seen in the equatorial region.

Uranus and Neptune

Four and a half years after visiting Saturn, the Voyager 2 spacecraft completed the first close-up observation of the Uranian system. The six-hour flyby revealed more information about Uranus and its retinue of icy moons than had been gleaned from ground observations since its discovery over two centuries ago by the English astronomer William Herschel.

Uranus, third largest of the planets, is the odd-ball of the solar system. Unlike the other planets, it lies tipped on its side with its north and south poles alternately facing the sun during its 84-year swing around the solar system. During Voyager's flyby, the south pole faced the sun.

Voyager found that the planet's magnetic field does not follow the usual north-south axis found on the other planets. Instead, it is tilted 60 degrees, and offset from the planet's center, a phenomenon that on Earth would be like having one magnetic pole in New York and the other in Jakarta.

Uranus's atmosphere consists mainly of hydrogen, with about 12 per cent helium and small amounts of ammonia, methane and water vapor. Wind speeds range up to 200 meters per second (447 mph), and blow from the west instead of the east as previously expected. Temperatures near the cloudtops measure −200 degrees C. (−329 degrees F.)

The sunlit south pole is shrouded in a kind of photo-chemical "smog" believed to be a combination of acetylene, ethane and other sunlight-generated chemicals. Surrounding the planet's atmosphere and extending thousands of kilometers into space is a mysterious ultraviolet sheen called an "electroglow."

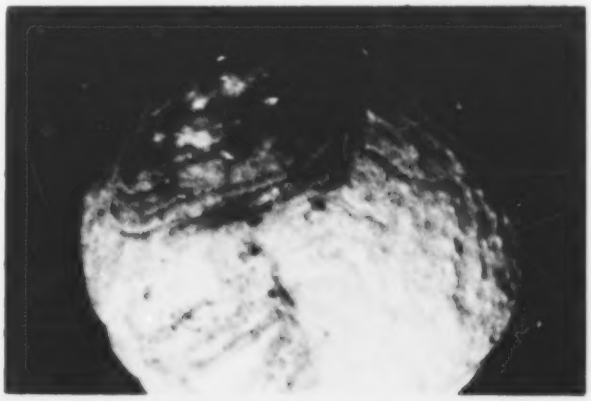
About 8,000 kilometers (5,000 miles) below Uranus's cloudtops there is thought to be a scalding ocean of water and dissolved ammonia some 10,000 kilometers (6,000 miles) deep. Beneath this ocean is an earth-sized molten core of heavier materials.

Voyager discovered 10 new moons orbiting Uranus, each about 40-170 kilometers (24-102 miles) in diameter. The planet's five known moons – Titania, Ariel, Miranda, Umbriel and Oberon – range in size from 480-1600 kilometers (300-1000 miles) across. The half-ice, half-rock spheres are a geological showcase, featuring twelve-mile-high mountains, jagged cliffs and canyons, crater-pocked plains and winding valleys possibly carved out by glaciers.

The planet was thought to have nine dark rings; Voyager found eleven. In contrast to Saturn's rings, which are composed of bright grain-sized particles, Uranus's rings are made up of boulder-sized chunks.

Voyager 2 will complete its Grand Tour of the solar system on August 25, 1989, when it sweeps to within about 1,280 kilometers (800 miles) of Neptune. The planet has two known moons, Nereid and Triton. The latter will be observed and photographed during the flyby. Neptune is the fourth largest of the planets and is believd to be a twin of Uranus.

Uranus as seen by Voyager 2's wide-angle camera. The images, taken through violet, orange and methane filters, show the concentric patterns of the planet's cloud layers. The view is toward the south pole.



The scarred face of Miranda, the smallest of Uranus's five major moons, indicates a violent past.

Pluto

Pluto is the most distant of the planets, yet the eccentricity of its orbit periodically carries it inside that of Neptune's. The orbit also is highly inclined – well above and below the orbital plane of the other planets.

Discovered in 1930, Pluto appears to be little more than a celestial snowball. Its diameter is calculated to be between 3,000 and 3,500 kilometers (1,864 and 2,175 miles), about the same as Earth's moon. Ground-based observations indicate that its surface is covered with methane ice.

The planet has one known satellite, Charon, discovered in 1978. There are no plans to send a probe to Pluto.

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Information Summaries

PMS 005 (KSC)
August 1986

Space Shuttle Mission Summary 1985-1986

STS Missions 51-C thru 51-L

Astronaut Sherwood Springs, working from a platform on the end of the Remote Manipulator System Canadarm, helps erect the EASE-ACCESS experiment on the deployment of large structures in space. Such experiments are vital to planners preparing the assembly of the Space Station in the early 1990s.

Space Shuttle Missions in Brief 1985-1986

MISSION NAME	ASTRONAUT	LAUNCH DATE	ORBITER	PRIMARY PAYLOAD	LAUNCH PAD	RESULT
STS 51-C	Mattingly, Shriver, Buchli, Onizuka, Payton	1/24/85	Discovery	DoD	39A	S
STS 51-D	Bobko, Williams, Seddon, Griggs, Hoffman, Garn, Walker	4/12/85	Discovery	Anik C-1/ SYNCOM IV-3	39A	S
STS 51-B	Overmeyer, Gregory, Lind, Thagard, Thornton, van den Berg, Wang	4/29/85	Challenger	Spacelab 3	39A	S
STS 51-G	Brandenstein, Creighton, Lucid, Nagel, Fabian, Baudry, Sultan Al-Saud	6/17/85	Discovery	Arabsat-1B/ Telstar 3-D/ Morelos 1	39A	S
STS 51-F	Fullerton, Bridges, Musgrave, England, Henize, Acton, Bartoe	7/29/85	Challenger	Spacelab 2	39A	S
STS 51-I	Engle, Covey, Van Hoften, Lounge, Fisher,	8/27/85	Discovery	AUSSAT 1/ ASC 1/ SYNCOM IV-4	39A	S
STS 51-J	Bobko, Grabe, Stewart, Hilmers, Pailes	10/3/85	Atlantis	DoD	39A	S
STS 61-A	Hartsfield, Nagel, Buchli, Bluford, Dunbar, Furrer, Ockels, Messerschmid	10/30/85	Challenger	Spacelab D-1	39A	S
STS 61-B	Shaw, O'Connor, Cleave, Spring, Ross, Vela, Walker	11/26/85	Atlantis	Morelos-2/ AUSSAT-2/ RCA Satcom Ku-2	39A	S
STS 61-C	Gibson, Bolden, Chang-Diaz, Hawley, Nelson, Cenker, Nelson	1/12/86	Columbia	RCA Satcom Ku-1	39A	S
STS 51-L	Scobee, Smith, McNair, Resnik, Onizuka, Jarvis, McAuliffe	1/28/86	Challenger	TDRS-B	39B	U

STS 51-C Mission

This was the first Space Shuttle mission totally dedicated to the Department of Defense. Its cargo was classified. Liftoff occurred on Jan. 24, 1985, at 2:40 p.m. EST, from Pad A at the Kennedy Space Center. The orbiter was Discovery. In addition to its payload the orbiter cargo bay carried an Inertial Upper Stage (IUS) booster that was deployed and successfully met its mission objectives, according to an official Air Force statement. The mission was completed in 3 days, one hour, and 33 minutes, landing at the Kennedy Space Center. The wheels stopped rolling at 4:23 p.m. on Jan. 27.

Crew. The crew members were Thomas C. Mattingly, commander. Loren J. Shriver, pilot; James F. Buchli and Ellison S. Onizuka, mission specialists; and Gary E. Payton of the U.S. Air Force, payload specialist.

STS 51-D Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 8:59 a.m. EST on April 12, 1985. This flight was a composite mission, carrying part of its original manifest and part of that from mission 51-E, which had been canceled. The crew was entirely from the canceled mission except for one of the two payload specialists, Charles Walker, who substituted for Patrick Baudry because the latter's flight experiments were no longer on the manifest. This mission also featured the first flight of an elected official, Senator E. J. "Jake" Garn (R-Utah), chairman of the Senate committee with oversight responsibilities for NASA's budget.

The Anik C-1 spacecraft was successfully deployed a few hours into the mission. Its PAM-D booster stage automatically fired 45 minutes later and lifted it into the planned elliptical geosynchronous transfer orbit. The Hughes SYNCOM IV-3 spacecraft, also called Leasat 3, was deployed on the second day in a routine operation. However, the booster stage did not fire as programmed. The orbiter returned to the vicinity and the crew examined the spacecraft. It was determined that the 'sequence start' lever, which should have been automatically opened during the deployment sequence, was apparently not fully erected. After consultation with Hughes, Mission Control in Houston directed the astronauts in the design of two 'flyswatter' devices capable of snagging and tugging on this lever. These were attached to the end of the Remote Manipulator System (RMS, or 'Canadarm') during an EVA by Griggs and Hoffman. The mission was extended two days to permit this try at activating the satellite. Seddon manipulated the Canadarm to hook the lever and tug hard on it, but this had no affect on the spacecraft. It was eventually repaired on a later mission (see Mission 51-I, following). Orbiter Discovery landed at KSC on April 19. The wheels stopped rolling at 8:55 a.m. EST, after a mission duration of 6 days, 23 hours, and 55 minutes. A tire blew out just before the end of the rollout, causing all following landings to be at Edwards AFB until the inactive nose wheel steering system could be activated and tested.

Crew. The crew members were Karol J. Bobko, commander; Donald E. Williams, pilot; M. Rhea Seddon, S. David Griggs, and Jeffrey A. Hoffman, mission specialists; and Charles D. Walker, McDonnell Douglas, and E. J. "Jake" Garn, United States Senate, payload specialists.

Payload and Experiments. The Anik C-1 was the third spacecraft in this series, C-2 and C-3 having been launched on pre-

vious STS missions. They are built by Hughes as part of its HS-376 series. Telesat of Canada assumed charge of its spacecraft after deployment, and later fired the onboard apogee motor to place it in geosynchronous orbit. SYNCOM IV-3 is also a Hughes spacecraft, the first specifically made to be deployed from a Space Shuttle orbiter. SYNCOM IV spacecraft are part of the Hughes HS 381 series. Each comes with its own built-in booster stage, identical to the third stage booster on the Minuteman missile, and two engines that burn monodimethyl hydrazine and nitrogen tetroxide. Both propulsion systems are required to place a SYNCOM IV in geosynchronous orbit. This series provides communications for the Department of Defense, under a contract granted to Hughes.

Other experiments included the second flight of the larger Continuous Flow Electrophoresis Experiment, successfully operated by Walker; an informal science study of the behavior of mechanical toys in microgravity; two Shuttle Student Involvement Project (SSIP) experiments, of which one was successful and one not; a Phase Partitioning Experiment; and echocardiograph and image intensifier experiments.

STS 51-D – Mission Specialists Jeffrey Hoffman (left) and Rhea Seddon demonstrate the behavior of a 'slinky toy' in microgravity.

STS 51-B Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 12:02 p.m. EDT on April 29, 1985. This was the second flight of the Spacelab, the first in a fully operational configuration. Spacelab capabilities for multidisciplinary research in microgravity were successfully demonstrated. The gravity gradient attitude of the orbiter proved quite stable, allowing the delicate experiments in materials processing and fluid mechanics to proceed normally. The crew operated in two 12-hr shifts. Two monkeys and 24 rodents were flown in special cages, the first time American astronauts have flown with live mammals aboard. The astronaut experimenters in orbit were supported 24 hours a day by a temporary Payload Operations Control Center, located at the Johnson Space Center. Challenger landed at Edwards AFB. Wheel motion stopped at 12:11 p.m. EDT on May 6, 1985, after a mission duration of 7 days, 0 hours and 8 minutes.

Crew. The crew members were Robert F. Overmyer, commander; Frederick D. Gregory, pilot; Don L. Lind, Norman E. Thagard and William E. Thornton, mission specialists; and Lodewijk van den Berg, of EG&G Energy Management, Inc., and Taylor G. Wang, of Jet Propulsion Laboratory, payload specialists.

Payload and Experiments. Spacelab 3 carried a large number of experiments, including 15 primary ones, of which 14 were successfully performed. There were five basic discipline areas – materials sciences, life sciences, fluid mechanics, atmospheric physics, and astronomy – with numerous experiments in each. Two Getaway Special experiments required that they be deployed from their canisters, a 'first' in this program. These were NUSAT (Northern Utah Satellite) and GLOMR (Global Low Orbiting Message Relay Satellite). NUSAT deployed successfully, but GLOMR did not deploy and was returned to Earth.

STS 51-B – Robert Overmyer aims a Linhof camera at the Earth through a flight deck window. The limb of the planet forms a vertical line directly above the camera.

STS 51-G Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 7:33 a.m. EDT on June 17, 1985. The largest items of cargo were three communications satellites. Also flown were the deployable/retrievable Spartan 1, six Getaway Special canisters, a High Precision Tracking Experiment (HPTE) for the Strategic Defense Initiative ("Star Wars"), a materials processing furnace, and French biomedical experiments.

All three communications satellites were successfully deployed and turned over to their owner-operators. Their PAM-D perigee booster motors fired and all three reached geosynchronous orbit, where they entered checkout operations. Spartan 1 was deployed and recovered. All the experiments were successfully accomplished. Discovery landed at Edwards AFB at 9:12 a.m. EDT on June 24, 1985, after a mission duration of 7 days, one hour and 39 minutes.

Crew. The crew members were Daniel C. Brandenstein, commander; John O. Creighton, pilot; Shannon W. Lucid, Steven R. Nagel, and John M. Fabian, mission specialists; and Patrick Baudry, France, and Prince Sultan Salman Al-Saud, Saudi Arabia, payload specialists.

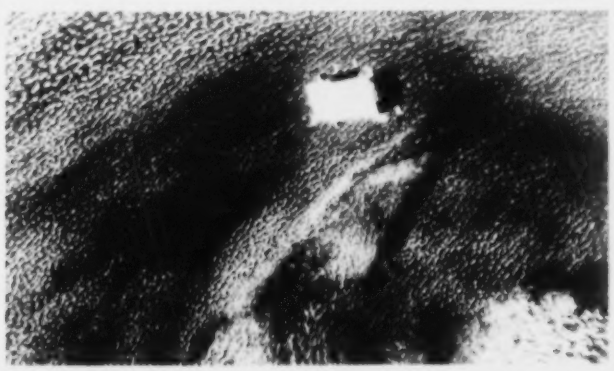
Payload and Experiments. The three communications satellites deployed were the Arabsat 1-B (Arab Satellite Communications Organization); Morelos 1 (Mexico); and Telstar 3-D (AT&T). All three utilized PAM-D booster stages to achieve geosynchronous transfer orbits after deployment from the Discovery. The latter two spacecraft are variants of the Hughes-built HS-376 series of spin-stabilized satellites. Both

use the Morton Thiokol Star 48 motor to circularize the orbit and align it with the equator at apogee. Morelos 1 provides 12 channels operating in the C-band and 6 channels operating in the Ku band. It can provide educational and commercial television programs, telephone and facsimile services, and data and business transmission services to even the most remote parts of Mexico. Telstar 3-D operates in the C-band only, and has 24 working channels. Using single sideband technology, a Telstar can relay up to 86,400 two-way telephone calls. Both spacecraft are about 22 ft high and 7 ft wide when deployed, and have a mass of around 1,450 lbs when operational.

Arabsat 1 satellites are built by an international team led by Aerospatiale of France. It is a three-axis stabilized spacecraft with two deployable solar array wings, making it almost 68 ft long and over 18 ft wide when deployed in orbit. It weighs about 2,800 lbs in its initial orbit, but some 1,490 lbs of this is propellant. It has an onboard low-thrust motor that utilizes hydrazine and nitrogen tetroxide, and transfers from an initial elliptical to geosynchronous orbit by firing this motor. The remaining propellant is then used for station-keeping or moving over the life of the satellite.

Spartan 1 measured 126 by 42 by 48 inches, and weighed 2,223 lbs. The Spartan is a carrier, designed to be deployed from the orbiter and fly free in space before being retrieved. Spartan 1 included 300 lbs of experiments in the field of astronomy. It was deployed and operated successfully, independent of the orbiter, before being retrieved.

STS 51-G – Payload Specialist Patrick Baudry of France (left) and Salman Al-Saud of Saudi Arabia conduct a French postural experiment in the middeck of Discovery.



STS 51-G – Spartan 1, a payload carrier with the capability of independent flight, maneuvers in space alongside Discovery.

The materials furnace, French biomedical experiments, and six Getaway Special experiments were all successfully performed, although the GO34 Getaway Special shut down prematurely. The Strategic Defense Initiative failed during its first try on orbit 37 because the orbiter was not at the correct attitude. It was successfully completed on orbit 64.

STS 51-F Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 5:00 p.m. EDT on July 29, 1985. The largest item of cargo aboard was Spacelab 2, the second and last Spacelab verification mission. Verification Flight Instrumentation (VFI) was strategically located throughout Spacelab 2 and at the Spacelab interfaces with the Orbiter Challenger. Spacelab 3, flown out of sequence ahead of Spacelab 2, was an operational mission, using essentially the same operating equipment already verified on Spacelab 1.

This mission was originally scheduled for launch on July 12, 1985. Main engine ignition was achieved on that date, but a malfunction in a coolant valve on the No. 2 engine resulted in the computer shutting down all three at T–3 seconds.

Liftoff on July 29 was delayed by approximately 1 hour and 37 minutes due to an orbiter problem. The flight then proceeded normally until the No. 1 engine shut down prematurely at 5 minutes and 45 seconds after liftoff. This resulted in an abort-to-orbit trajectory and an initial orbital altitude of 124 by 165 miles. This was later corrected by OMS burns to reach an altitude of 196 by 197 miles.

Once in orbit the mission went well, with good results being obtained by all major experiment instruments. The mission was extended to eight days from the planned seven, to obtain more data. Challenger landed at Edwards AFB at 3:45 p.m. EDT on August 6, 1985, after a mission duration of 7 days, 22 hours and 45 minutes.

Crew. The crew members were Charles G. Fullerton, commander; Roy D. Bridges, pilot; F. Story Musgrave, Anthony W. England and Karl G. Henize, mission specialists; and Loren W. Acton, Lockheed Corporation, and John-David Bartoe, Naval Research Laboratory, payload specialists.

Payload and Experiments. The VFI system operated normally during launch and ascent, obtaining good data which was relayed to the ground later via the TDRS. The VFI instruments continued to operate normally throughout the mission. All of the 13 planned detailed test objectives were accomplished.

This was the first Spacelab mission where most instruments were mounted on a three-pallet train and open to space. A separate container protected one large experiment, on the elemental composition and energy spectra of cosmic ray nuclei, located behind the pallet train at the rear of the cargo bay. To provide the fine pointing accuracy needed by the solar and astronomy experiments on pallet 1, an Instrument Pointing System (IPS), developed by the European Space Agency, was flown on this mission. The IPS features a threeaxis gimbal system that can orient instruments of up to 4,400 pounds mass within an accuracy of 1 arc second. During Verification Flight Testing of the IPS some problems occurred in acquiring

and fine tracking of the Sun, using the optical sensor package. Onboard troubleshooting enabled the development on the ground of a series of software patches that corrected the problem.

Four experiments were conducted inside the pressurized crew compartment. Two dealt with Vitamin D metabolites and bone demineralization, which included taking physiological measurements of the flight crew members. A third was to determine the effect of weightlessness upon lignification in plants. The fourth, added late in mission planning, dealt with protein crystal growth. All were highly successful.

The pallet-mounted instruments conducted experiments or gathered data in the areas of plasma physics, infrared astronomy, high-energy physics, solar physics, atmospheric physics, and technology. The instruments were operated by the crew from inside the pressurized compartment, or by ground control. A special part of the modular Spacelab system located at the head of the train, called the Igloo, provided on-site support services to the instruments mounted on the pallets. These support subsystems are designed to operate in a pressurized environment, and the Igloo is the only part of this configuration of the Spacelab that requires pressurization. The equipment in the Igloo can vary. For this mission it included three computers, one mass memory, a power controller, subsystem power distribution, multiplexer, a freon cooling loop, and other support components.

The highly trained Spacelab-2 crew carried out experiments for which there were few precedents except rehearsals. The crew held frequent conversations with experts on the ground. As a result, the data and images acquired appear to be of very high quality.

STS 51-F — The Instrument Pointing System uses star locations for stable reference points and then furnishes guidance to the sensitive astronomical instruments aboard Spacelab 2.

STS 51-I Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 6:58 a.m. EDT on August 27, 1985. The cargo consisted of three communications satellites and one middeck experiment. The launch was originally planned for August 24, but was delayed due to thunderstorms and lightning in the pad areas. It was further delayed until August 27 to replace a failed General Purpose Computer (No. 5) and to inspect the main engine ducts. This mission had the unusual responsibility of capturing and repairing a spacecraft, SYNCOM IV-3 (deployed on the earlier Discovery mission 51-D the previous April), after first deploying SYNCOM IV-4.

The remaining two spacecraft were AUSSAT-1 and American Satellite Company 1 (ASC-1). The AUSSAT sunshield hung up on the satellite's omni antenna when an attempt was made to reopen the sunshield to perform a spacecraft health check. The Canadarm was then used to open the deformed sunshield. To avoid more heat from sunlight than was allowable on the spacecraft and attached booster stage, AUSSAT-1 was deployed a day early, on August 27. ASC-1 was deployed the same day.

SYNCOM IV-4 was deployed on August 29. A scheduled backup day was not needed, enabling SYNCOM IV-3 rendezvous maneuvers to begin a day earlier than planned. Fisher and Van Hoften performed an EVA to capture the satellite on Flight Day 5. Power had been lost on the Canadarm elbow joint, when operating in the primary mode, on the first day. This limitation caused operations to go slowly. A second EVA was required the next day. The installation of a bypass system to provide ground control of the spacecraft was successfully completed. At a later date, the satellite was placed in the correct orbit and entered normal service.

Orbiter Discovery landed at VAFB on September 3, 1985; the wheels stopped rolling at 9:16 a.m. EDT. The mission duration was 7 days, 2 hours and 18 minutes.

Crew. The crew members were Joe H. Engle, commander; Richard O. Covey, pilot; and James Van Hoften, John M. Lounge and William F. Fisher, mission specialists.

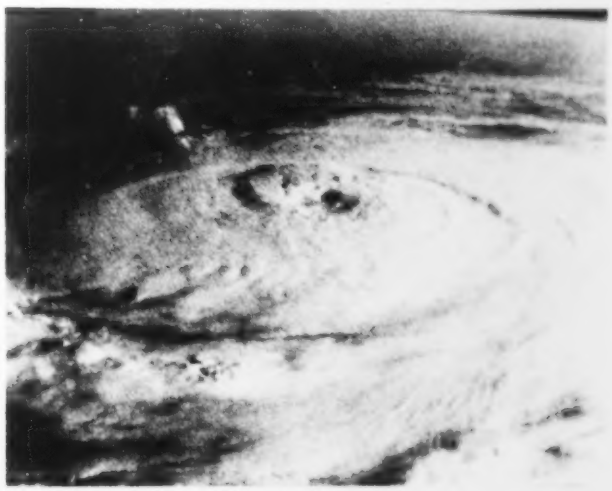
Payload and Experiments. Two of the three communications spacecraft, AUSSAT-1 and ASC-1, were equipped with a PAM-D booster stage. The third, SYNCOM IV-4, utilizes a Minuteman third stage as a booster. See mission 51-D for a more complete description of a SYNCOM IV.

The AUSSAT system is designed to provide a wide range of domestic communications services to the entire continent of Australia and its offshore islands. This includes direct television broadcasts to isolated homesteads and remote communities, high quality television relays between major cities, digital data transmission for business use, centralized air traffic control services, and maritime and land-based radio

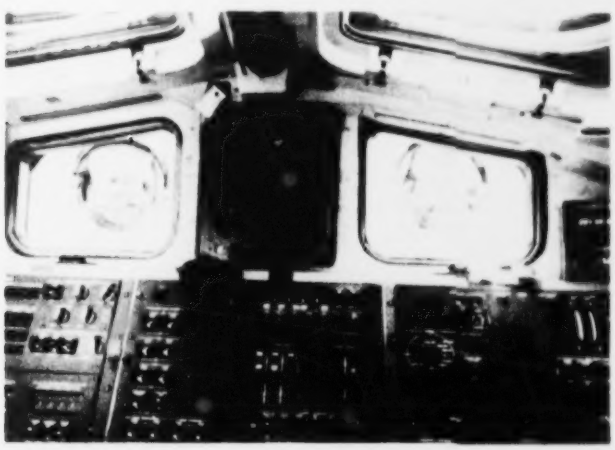
coverage. AUSSAT-1 is a Hughes HS 376 model, and operates 15 channels in the 14/12 GHz Ku band.

The ASC-1 satellite provides voice, data, facsimile, and videoconferencing communications services to U.S. businesses and government agencies. It is a hybrid spacecraft, providing channels in both the 6/4 and 14/12 GHz bands. A unique 'first' for the ASC series is their encrypted command links, a security feature which guards against unauthorized access to the satellite command system. ASC spacecraft are built by RCA Astro Electronics.

The payload item in the pressurized crew compartment was the second in a series by the 3M Company, dealing with the Physical Vapor Transport of Organic Solids (PVTOS). The experiment was conducted successfully.



STS 51-I — An oblique view of Hurricane Elena taken September 2, 1985, from the flight deck of Discovery. The structure of almost the entire storm can be seen in this single photograph.



STS 51-I — During a light moment Mission Specialists William Fisher (left) and James van Hoften, hovering in space, peer into the crew compartment of Discovery through two front windows.

STS 51-J Mission

This was the second Space Shuttle mission totally dedicated to the Department of Defense. Its cargo was classified. Liftoff occurred on October 3, 1985, at 11:15 a.m. EDT, from Pad A, Launch Complex 39, Kennedy Space Center. The orbiter was Atlantis, making its first flight. The mission was classified as "Successful." After a duration of 4 days, 1 hr and 45 minutes, Atlantis landed on Runway 23 at Edwards AFB at 1:00 p.m. EDT on October 7, 1985.

Crew. The crew members were Karol J. "Ro" Bobko, commander; Ronald J. Grabe, pilot; David C. Hilmers and Robert L. Stewart, mission specialists; and William Pailes, U.S. Air Force, payload specialist.

STS 61-A Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 12:00 noon EST on October 30, 1985. This was the first Space Shuttle mission largely financed and operated by another nation, West Germany. It was also the first Space Shuttle flight to carry a crew of eight. The primary mission was to operate a series of experiments, almost all related to functions in microgravity, in Spacelab D-1, the fourth flight of a Spacelab. Two other mission assignments were to deploy the Global Low Orbiting Message Relay Satellite (GLOMR) out of a Getaway Special canister in the cargo bay, and operate five materials processing experiments mounted in the cargo bay on a separate device called the German Unique Support Structure.

NASA operated the Space Shuttle, and was responsible for overall safety and control functions throughout the flight. West Germany was responsible for the scientific research carried out during the seven-day mission. To fulfill this function German scientific controllers on the ground worked closely with the personnel in orbit, operating out of the German Space Operations Center at Oberpfaffenhofen, near Munich, West Germany. The orbiting crew divided into two teams, and operated 24-hrs a day. Communications were very good throughout the mission and the ground and orbital crews were able to interact regularly. The overall system of one Center controlling spacecraft operations and a second controlling experiment functions worked very smoothly in practice.

The GLOMR satellite was successfully deployed during the mission. The five experiments mounted on the separate structure behind the Spacelab module obtained good data. Orbiter Challenger landed on Runway 17 at Edwards AFB on November 6, 1985. The wheels stopped rolling at 12:45 p.m. EST, after a mission duration of 7 days, 0 hours, and 45 minutes.

Crew. The crew members were Henry W. Hartsfield, Jr., commander; Steven R. Nagel, pilot; Bonnie J. Dunbar, James F. Buchli and Guion S. Bluford, mission specialists; and Ernst Messerschmid and Reinhard Furrer, West Germany, along with Wubbo Ockels, European Space Agency, payload specialists.

Payload and Experiments. The science research effort on Spacelab D-1 encompassed some 75 numbered experiments,

most of which were performed more than once. Some of these experiments had predecessors which had returned data obtained on earlier flights. This made it possible to prepare experiment regimens that were 'second generation' with respect to technical concept and experiment installation. Almost all of them took advantage of the microgravity environment to perform work not possible, or very much more difficult to do, on Earth. The major area of concentration was materials science, in which West Germany has a well developed expertise.

The primary areas of experiment concentration were: fluid physics, with experiments in capillarity, Marangoni convection, diffusion phenomena, and critical point; solidification experiments; single crystal growth; composites; biological, including cell functions, developmental processes, and the ability of plants to perceive gravity; medical, including the gravitational perceptions of humans, and their adaptation processes in space; and speed-time interaction studies of people working in space.

One equipment item of unusual interest was the Vestibular Sled, an ESA contribution consisting of a seat for a test subject that could be moved backward and forward with precisely controlled accelerations and stops, along rails fixed to the floor of the Spacelab aisle. By taking detailed measurements on a human strapped into the seat, scientists gained data on the functional organization of the human vestibular and orientation systems, and the vestibular adaptation processes under microgravity. The acceleration experiments by the sled riders were combined with thermal stimulations of the inner ear and optokinetic stimulations of the eye.

Overall, this was the most comprehensive series of experiments to date on materials processing in space and associated human activities, adding a rich store to humanity's knowledge. The data that was gained will require years of analysis.

STS 61-A — Payload Specialist Wubbo Ockels, European Space Agency, lifts himself out of a special sleeping bag designed by a Dutch company that let him be the first person to sleep inside a Spacelab instead of the orbiter.

STS 61-B Mission

The Orbiter Atlantis lifted off from Pad A, Launch Complex 39, KSC, at 7:29 p.m. EST on November 26, 1985, the second night launch in the Shuttle program and the second flight for Atlantis. The primary payload of three communications satellites were successfully deployed, one at a time, and a major demonstration of construction techniques to build structures in orbit was successfully accomplished. This activity was filmed by an IMAX large-film camera mounted in the cargo bay, obtaining some excellent coverage. Three experiments located in the pressurized crew compartment were also completed, with good data obtained. The landing was at Edwards AFB, at 4:33 p.m. EST on December 3, 1985, after a mission duration of 6 days, 21 hrs, and 5 minutes.

Crew. The crew members were Brewster H. Shaw, Jr., commander; Bryan D. O'Connor, pilot; Mary L. Cleave, Sherwood C. Spring and Jerry L. Ross, mission specialists; and Rodolfo Neri Vela, Mexico, and Charles Walker, McDonnell Douglas, payload specialists.

Payload and Experiments. Two of the three communications satellites were AUSSAT-2 and Morelos-B, in each case the second in its series. (See mission 51-I and 51-G.) Both were Hughes HS-376 satellites equipped with a PAM-D booster to reach geosynchronous transfer orbit. The third spacecraft was the SATCOM Ku-2, a version of the RCA 4000 series. RCA American Communications owns and operates the satellite system of which SATCOM Ku-2 is a part. It was attached to a PAM-D2 booster, a larger version of the PAM-D. This was the first flight of this booster stage on a Space Shuttle.

All three spacecraft were successfully deployed, one at a time, and their booster stages fired automatically to lift them to geosynchronous transfer orbits. Their respective owners assumed charge, and later fired the onboard kick-motors at apogee, to circularize the orbits and align them with the equator.

SATCOM Ku-2 has 16 channels and operates entirely in the Ku (14/12 GHz) range. Each channel has an output power of 45 watts and a bandwidth of 54 MHz, enough to make reception practical on a home antenna as small as three feet in diameter. This was the first of three spacecraft planned to form a complete operating system. Future planned service areas are homes that cannot receive cable television services, multi-unit residential complexes such as condominiums and apartment houses, hotels, hospitals, and schools; and a syndication system to deliver time-sensitive programming to commercial broadcast television stations.

An item of major interest was EASE/ACCESS, an experiment in assembling large structures in space. ACCESS was a 'high-rise' tower composed of many small struts and nodes. EASE was a geometric structure shaped like an inverted pyramid, composed of a few large beams and nodes. Together they demonstrated the feasibility of assembling large preformed structures in space. The IMAX camera mounted in

the cargo bay filmed the activities of the astronauts engaged in the EASE/ACCESS work, as well as other scenes of interest.

Rudolfo Neri Vela accomplished a series of experiments, primarily in human physiology. Charles Walker again operated the Continuous Flow Electrophoresis System, the third flight of this larger and improved equipment to produce commercial pharmaceutical products in microgravity. An experiment in Diffusive Mixing of Organic Solutions, or DMOS, was operated successfully for the 3M Company. The object is to grow single crystals in microgravity that are larger and more pure than any that can be grown on Earth. One Getaway Special canister in the cargo bay carried an experiment by Canadian students to fabricate mirrors in microgravity with higher performance than ones made on Earth.

All the experiments on this mission were successfully accomplished, and all equipment operated within established parameters.

STS 61-C Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 6:55 a.m. EST on January 12, 1986. This launch had been postponed several times from an originally planned date of December 18. On that date it was delayed to December 19 because of excess time needed to close out the aft compartment. On December 19 the count was halted at T–14 seconds due to an out-of-tolerance reading on the right solid rocket booster hydraulic system. Another launch attempt on January 6 was halted at T–31 seconds due to a problem with the fill and drain valve in the liquid oxygen system; the window ended before the problem could be resolved. On January 7 the launch team tried again, but marginal weather for an emergency return to KSC plus bad weather at the emergency landing sites at Dakar and Moron forced a postponement. The January 9 planned launch was delayed an extra day to permit removal of an obstruction in the Space Shuttle Main Engine No. 2 liquid oxygen prevalve. On January 10 another launch attempt was made, but eventually called off due to heavy rains in the pad area. The actual liftoff on January 12 was then achieved without major incident.

The primary payload of the RCA Ku-1 satellite was successfully deployed. Most of the large number of small payloads and experiments in the cargo bay and crew compartment were successfully operated. One exception was the Comet Halley Active Monitoring Program (CHAMP), which did not function properly due to battery problems.

Mission controllers decided to shorten the planned flight by one day to provide more processing time on the ground for the next flight of Columbia, bringing it in at KSC on January 16. The landing attempt had to be waved off on that day due to unfavorable weather at KSC, and was waved off again the next day as well. The mission was extended one more day for another KSC attempt, but when it also had to be waved off because of weather, Columbia landed at Edwards AFB instead. The wheels stopped rolling at 8:59 a.m. EST on January 18, after a mission duration of 6 days, 2 hours, and 4 minutes.

Crew. The crew members were Robert L. Gibson, commander; Charles F. Bolden, Jr., pilot; Franklin Chang-Diaz, Steven A. Hawley, and George D. Nelson, mission specialists; and Robert Cenker, RCA Astro-Electronics, and Bill Nelson, United States House of Representatives, payload specialists.

Payload and Experiments. This mission carried an unusually large number of small experiments. The one large item was the SATCOM Ku-1, the second in this series of communications satellites for RCA Americom (see Mission 61-B for a description of the spacecraft and its attached PAM-D2 booster stage). There were 13 Getaway Special canisters, 12 mounted on a GAS Bridge Assembly that reaches from side to side across the cargo bay, and one attached to the GAS canister mounts on the right wall nearby. These provided a wide variety of experiments, including ones in microgravity dealing with materials processing, seed germination, egg hatching, and chemical reactions; astronomy observations; and atmospheric physics experiments.

A second experiment carrier that reaches across the cargo bay was flown for the first time, the Materials Science Laboratory-2 structure. It carried three larger experiments exploring liquid bubble suspension by sound waves, melting and resolidification of metallic samples, and containerless melting and solidification of electrically conductive specimens.

A third small payloads carrier called the Hitchhiker G–1 (HHG–1) attached to two GAS canister mounts on the cargo bay right wall near the front. It carried three experiments, to film particles in the local environment, test a new heat transfer system, and determine the effects of contamination and atomic oxygen on ultraviolet optics materials.

Three experiments in the pressurized crew compartment were by students working in the Shuttle Student Involvement Program, and dealt with the measurement of auxin levels and starch grains in plant roots, air injection as an alternative to honeycombing in metals, and a study of paper fiber formation in microgravity. Another cabin experiment measured the sedimentation level of whole blood stored in microgravity.

The CHAMP experiment consisted primarily of a 35mm camera to photograph Comet Halley through the aft flight deck overhead window. This experiment was not successful.

STS 51-L MISSION

The Orbiter Challenger lifted off from Pad B, Launch Complex 39, KSC, at 11:37 a.m. on January 28, 1986. At just under 74 seconds into the flight an explosion occurred, which caused the loss of the vehicle and its crew.

Crew. The crew members were Francis R. Scobee, commander; Michael J. Smith, pilot; Judith A. Resnik, Ellison Onizuka, and Ronald E. McNair, mission specialists; and S. Christa McAuliffe, New Hampshire schoolteacher, and Gregory B. Jarvis, Hughes Aircraft, payload specialists.

Payload and Experiments. The primary item of cargo was the second Tracking and Data Relay Satellite (TDRS), with an attached Inertial Upper Stage (IUS) booster for the planned transfer to geosynchronous orbit. Also aboard was the Spartan, a free-flying module designed to operate independently of the orbiter and observe Halley's Comet with two ultraviolet spectrometers and two cameras. Several small experiments were carried in the pressurized crew compartment, including a set of lessons planned for live television transmission by S. Christa McAuliffe, a teacher and the first passenger–observer in the U.S. manned space program.

NASA Information Summaries

National Aeronautics and
Space Administration

PMS-019 (JSC)
December 1986

Astronaut Selection and Training

By the mid 1990's, Americans will be living and working in space. The science fiction characters of yesteryear will come to life as flesh and blood astronauts, scientists, technicians, and specialists engaged in transportation, servicing, manufacturing, and research. Men and women who man the Space Station will learn to adapt to the peculiarities of life in a weightless environment where they float from place to place, add a dab of water to make freeze-dried meals come to life, and shower with floating globules of water. The frontiers of space are continually moving outward and Space Station is man's next step into the universe.

History of Astronaut Selection

Man's scope of space exploration has broadened since the first U.S. manned space flight in 1961. But the Nation can never forget the original seven space pilots who focused our vision on the stars. In 1959, the National Aeronautics and Space Administration (NASA) asked the U.S. military services to list their members who met specific qualifications. In seeking its first astronauts, NASA required jet aircraft flight experience and engineering training as well as height below 5 feet 11 inches because of limited cabin space available in the Mercury space capsule being designed. After many series of intense physical and psychological screenings, NASA selected seven men from an original field of 500 candidates. They were Lieutenant M. Scott Carpenter, Air Force Captains L. Gordon Cooper, Jr., Virgil "Gus" Grissom, and Donald K. "Deke" Slayton; Marine Lieutenant Colonel John H. Glenn, Jr.; and Navy Lieutenant Commanders Walter M. Schirra, Jr. and Alan B. Shepard, Jr.

Each man flew in Project Mercury except Slayton, who was grounded for medical reasons. Sixteen years later, Slayton was an American crewmember of the Apollo-Soyuz Test Project, the world's first international manned space flight.

Nine pilot astronauts were chosen in September 1962, and fourteen more were selected in October 1963. By then, prime emphasis had shifted away from flight experience and toward superior academic qualifications. In October 1964, applications were invited on the basis of educational background alone. These were the scientist astronauts, so called because the 400-plus applicants who met minimum requirements had a doctorate or equivalent experience in the natural sciences, medicine, or engineering. Of these 400 applicants, six were selected in June 1965.

In April 1966, 19 pilot astronauts were named and in August 1967, 11 scientist astronauts were added to the program. When the Air Force Manned Orbiting Laboratory program was cancelled in mid-1969, seven astronaut trainees transferred to NASA.

Shuttle Era Astronaut Candidate Recruiting

The first group of astronaut candidates since the Space Shuttle Program began was selected in January 1978. In July of that year, they began a rigorous training and evaluation period at NASA's Johnson Space Center to qualify for subsequent assignment for future Space Shuttle flight crews. This group of 20 mission specialists and 15 pilots completed training and went from astronaut candidate status to astronaut (active status) in August 1979. Six of the 35 were women and four were members of minorities.

Three groups of pilots and mission specialists have been added since then: 19 in July 1980, 17 in July 1984, and 13 in August 1985.

SPACE TRANSPORTATION SYSTEM

One of the goals of the Space Transportation System (STS) is the expansion of the Nation's research capabilities in the space environment. The STS provides the opportunity for onboard participation of scientific investigators or other representatives of the payload research community, as well as individuals selected by major payload customers who reimburse NASA. The participation of these payload specialists, as they are called, enhances the probability of successful achievement of their scientific or technical mission objectives.

Space Shuttle Crew Positions

Pilot Astronauts

Pilot astronauts serve as both Space Shuttle commanders and pilots. During flight, the commander has onboard responsibility for the vehicle, crew, mission success, and safety of flight. The pilot assists the commander in controlling and operating the vehicle. In addition, the pilot may assist in the deployment and retrieval of satellites using the robot arm in spacewalks, and in other payload operations.

Mission Specialist Astronauts

Mission specialist astronauts, working with the commander and pilot, have overall responsibility for the coordination of Space Shuttle operations in the areas of crew activity planning, consumables usage, and experiment and payload operations. Mission specialists are required to have a detailed knowledge of the Space Shuttle systems, as well as detailed knowledge of the operational characteristics, mission requirements and objectives, and supporting systems and equipment for each of the experiments to be conducted on their assigned missions. Mission specialists perform spacewalks and payload handling using the robot arm, and perform or assist in specific experiment operations.

Payload Specialists

Payload Specialists are primarily professionals in the physical and life sciences, or technicians skilled in the operation of unique equipment. The selection of a payload specialist for a particular mission is the responsibility of the payload sponsor or customer. In the case of a NASA-sponsored mission, payload specialist candidates are identified by an Investigator Working Group (IWG), and final selection is approved by NASA. Payload specialists who fly in support of a major payload customer are selected directly by the sponsoring company or organization. They need not be U.S. citizens. All selected individuals must comply with NASA-established health and physical fitness standards.

Once accepted, the payload specialist undergoes dual training. Training related to the operation of the payload or experiment may take place at an industrial facility, a university, or a government agency. The second type of training — flight familiarization — is required for every mission and takes place at the Johnson Space Center. This flight training familiarizes the payload specialist with the Space Shuttle and payload support equipment, crew operations, housekeeping, and emergency procedures related to his or her flight.

For information about opportunities in this field, write to NASA Headquarters, Attn: Code OST-5, Washington, D.C. 20546. If you are not a citizen of the United States, you may instead wish to contact the appropriate government agency within your own country.

Astronaut Candidate Program

The National Aeronautics and Space Administration accepts applications on a continuous basis and selects astronaut candidates as needed. Civilians and military personnel are considered for the one-year training program. Current regulations require that preference for appointment to vacant positions be given to U.S. citizens when they are available. For information on pilot astronaut or mission specialist opportunities, write to Astronaut Selection Office, Mail Code AHX, Johnson Space Center, Houston, Texas 77058.

General Program Requirements

Selected applicants are designated astronaut candidates and are assigned to the Astronaut Office at Johnson Space Center. During the one-year training and evaluation period, they are assigned technical or scientific responsibilities and they participate in the astronaut training program designed to develop the knowledge and skills required for formal mission training upon selection for a flight. Final selection is made after the one-year program.

Basic Qualification Requirements

For mission specialists and pilot astronaut candidates, the basic education requirement is at least a bachelor's degree with major study in engineering, biological science, physical science, or mathematics from an accredited college or university. Mission specialist applicants must also have 3 years of professional, related experience. Pilot astronaut candidates must have at least 1,000 hours pilot-in-command time in jet aircraft. Payload specialists must have the appropriate education and training related to the payload or experiment. All applicants must meet certain physical requirements and must pass NASA space physical examinations with varying standards depending on classification.

Training Activities

Once selected, astronauts have a busy schedule of schooling and training in preparation for space flight. They study basic science and technology courses such as mathematics, Earth resources, meteorology, guidance and navigation, astronomy, physics, and computers.

For astronauts to learn to live and work in a weightless environment, they train for functioning in zero-gravity with various simulation experiences. The KC-135 jet aircraft, modified for astronaut training, gives the effect of a rapidly descending elevator when flown "over the top" of a parabolic path. During this zero-gravity period lasting about 30 seconds, astronauts practice drinking, eating, and using various types of equipment. Longer periods of weightlessness are simulated under conditions of "neutral buoyancy" in a specially designed water tank large enough to hold full-scale mockups of spacecraft components and equipment.

To become accustomed to working in a pressurized space suit, astronauts spend many mission training sessions in the suit.

Space Shuttle pilot astronauts land the spacecraft much like an aircraft on a runway. Therefore, conventional and modified aircraft are used to practice approach and landings. The four-engine KC-135 jet provides experience in handling large, heavy aircraft and the modified Grumman Gulfstream II aircraft, designated "Shuttle Training Aircraft" (STA), simulate the handling characteristics of the Orbiter for landing practice.

Through attendance at engineering conferences and review meetings, astronauts keep informed about spacecraft, payload, and launch vehicle design, development, and modification activities.

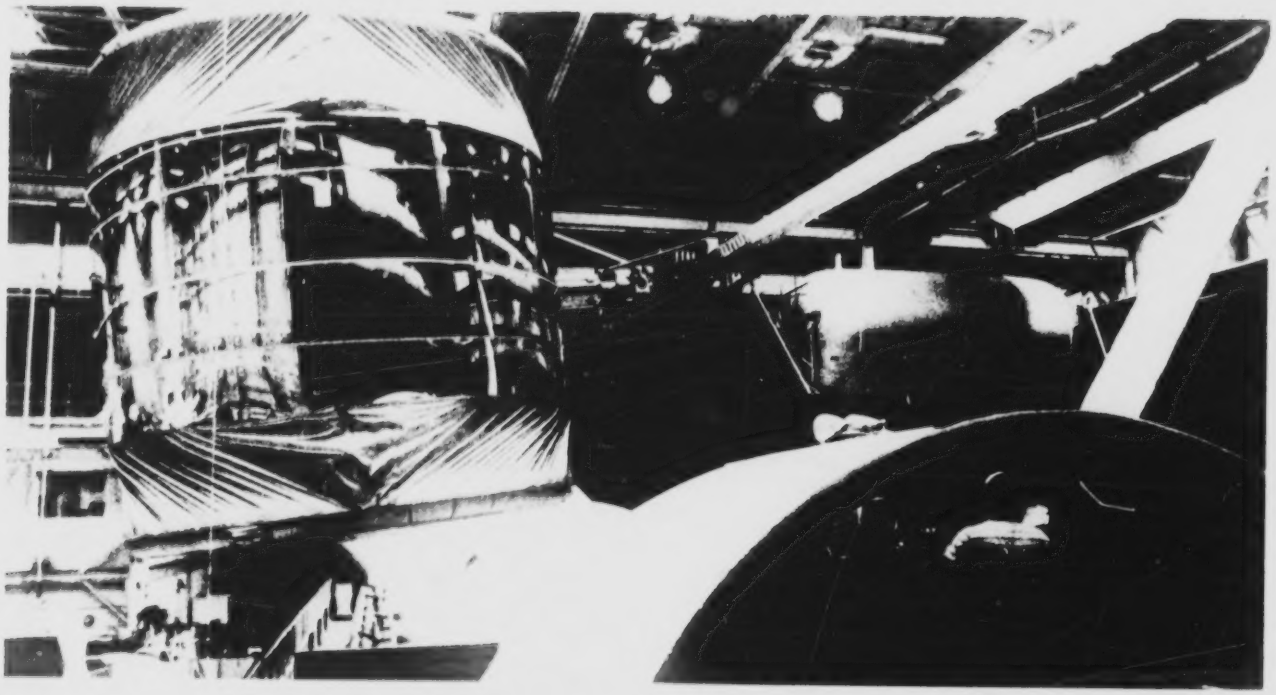
Astronauts maintain flight readiness through regular use of high-performance aircraft assigned to the Johnson Space Center and based at nearby Ellington Field. Physical conditioning, for both pilot astronauts and mission specialists, is a matter of individual need and preference. Gymnasium facilities are available.

Flight Assignments

When assigned to a flight crew, an astronaut undertakes a busy schedule. Crews are named for specific flights well in advance of the launch date and because of the frequent flights of the Space Shuttle, several crews may be in training at the same time.

Each crew receives cross-training so that at least one crewmember can handle the most critical duties of each associate. Thus, an ill or injured crewmember can be relieved in flight without compromising the mission.

Each crew takes part in spacecraft reviews and test programs that let each crewmember become familiar with a spacecraft. These reviews include briefings on the spacecraft, the spacecraft systems, and guidance and navigation.



The tempo picks up as the astronauts begin working with the various simulators, first to learn the individual tasks that are required to fly the spacecraft, then to put them all together in the sequence that will be followed during the actual mission.

The simulators provide extremely realistic working conditions. The spacecraft interiors are duplicated, and the instruments, such as guidance and navigation displays, are programmed to give the same readings they would in flight. Even out-the-window views of the Earth, stars, payloads, and the landing runway are projected onto screens where the spacecraft windows would be. The simulated conditions are so accurate that most astronauts come back from a mission feeling they had made the same flight many times before.

Training reaches a peak about 10 weeks before the scheduled flight when the mission simulator is linked with the Mission Control Center and with an also-simulated version of the network of tracking stations. Crews and flight controllers practice the most important portions of the mission in a series of joint training exercises that prove everything is ready for the real flight.

In between their simulator sessions, the crewmembers continue to keep themselves up to date on the status of the spacecraft and payloads for their mission. They also practice activities related to the mission, such as deploying and retrieving payloads, operating experiments, and performing extravehicular activity. They train in celestial navigation — important to spacecraft navigation and in the performance of some of the scientific experiments. They learn detailed scientific equipment design and operation in gathering scientific data. And all the while, each astronaut continues to maintain proficiency in flight and physical status.

Even when the flight is completed, the job is not done. The crewmembers spend several days in debriefing — recounting their experiences for the benefit of future crews to help determine whether spacecraft systems, payload handling techniques, or perhaps training procedures might be improved. Members of the media also receive a detailed postflight briefing by the crew. And, after a brief "vacation," the studies and training that eventually may lead to another flight into space are resumed.

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NASA-JSC

NASA

National Aeronautics and
Space Administration

Information Summaries

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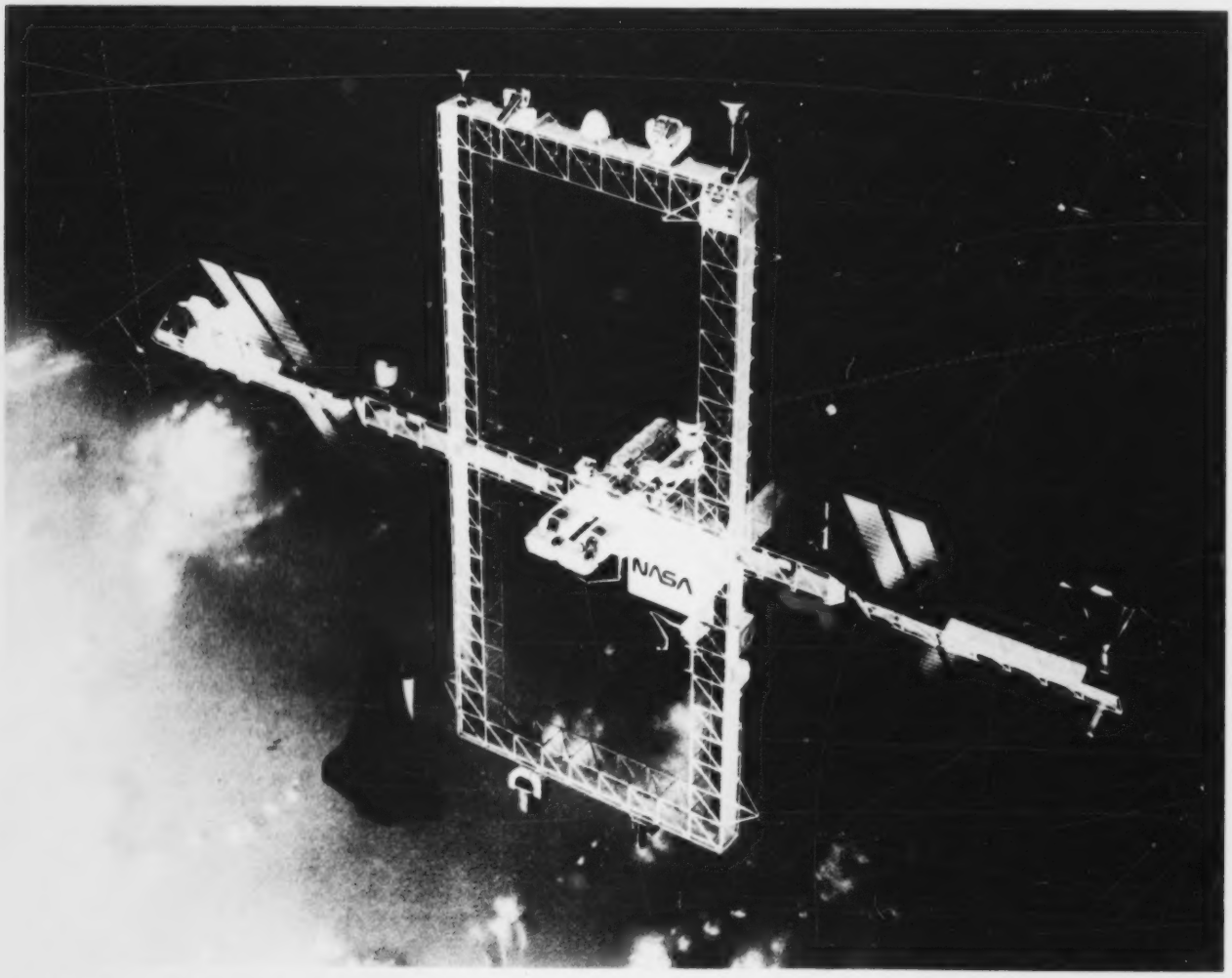
December 1986

Space Station



A shuttle orbiter prepares to berth at the permanently manned Space Station hovering 300 miles above the Earth in this dramatic artist concept. Being developed by NASA, the Space Station will serve the needs of science, technology and private sector when placed in operation in the mid 1990's.

At the center of the Space Station are the pressurized modules where crews will work and live. The two United States modules are depicted: one a laboratory module and the other a habitat module. Also shown is the proposed Japanese experiment module. Alongside the Japanese module is the proposed European Space Agency module. Remote manipulator arms, provided by Canada, are located on the truss structure. Off in the distance is a Space Station co-orbiting platform. An Orbital Maneuvering Vehicle (OMV) is shown flying out toward the platform.

The history of America's manned space program for the past two and a half decades has been built upon a series of logical steps. Man's first trips into space were short, daring feats made by men of unsurpassed skill and courage. They went into space for one reason—to determine if man could survive in the hostile environment.

Spurred by presidential direction that America should land a man on the Moon and return him safely to the Earth, longer space flights were conducted to prove that man could perform the intricate maneuvers that would be required to achieve a lunar landing. Finally, the goal was reached. Man, for a short period, inhabited another heavenly body.

Even before man took his first cautious steps into space, he had dreamed of a permanent outpost in orbit which could be used for observing the Earth and the heavens, or as a jumping off spot for missions to other planets and galaxies. America's first Space Station was called Skylab, a converted third stage of a left-over moon rocket. The modest orbiting laboratory was visited by three crews of astronauts who stayed as long as three months, proving that man could live and work in space.

The notion of a space station is not new or revolutionary. The Soviet Union has for several years operated several versions of a space station, and recently placed into orbit a new space station which they call Mir, the Russian word for peace. The Soviets have indicated they intend to occupy Mir permanently and make it the core of a busy complex of space-based factories, construction and repair facilities and laboratories.

When the Space Shuttle was conceived in the late 1960's, a space station was envisioned as a natural complement, a place for the orbiter to shuttle. The Space Station, and its infrastructure, the key to future operations in space, could not be built without a safe, reliable and efficient Shuttle. Having learned from the Challenger tragedy the bitterest of lessons, NASA is committed to a better, safer Shuttle system which will give us back the ability, a first for mankind, to fly off and back on to our planet in order to utilize the potential of space for the benefit of mankind.

Man has accomplished much in the brief span of time since he first began exploring space, yet he has really only scratched the surface. More than a quarter century has passed since the first rocket was launched from Cape Canaveral, yet the actual time spent on orbit, experimenting and learning, has been but a fraction of that. The visits are too brief. Man needs a permanent facility in orbit to permit him to stay and to work for as long as the work requires. A permanently manned Space Station is the next logical step.

In his State of the Union message of January 25, 1984, President Reagan announced a new, imaginative and far-reaching plan for America's space program, a plan that will carry the program well into the 21st century.

He directed NASA to develop a permanently manned Space Station and to do it within a decade.

The President's Space Station directive underscores a national commitment to maintaining United States leadership in space. Such leadership is essential, for America has become dependent upon operations in space: for communications, resource analysis and weather reports; for the conduct of science and the development of new technologies; and for the national security of our country. Space is no longer an unknown, unreachable environment. It is simply a place to conduct useful, necessary activities. A place for men and women to live, work and learn.

Continued U.S. leadership in space is but one reason why a Space Station should be built. From a comparatively modest investment (about one-ninth the investment in Project Apollo and about one-third the investment in Space Shuttle), it offers extraordinary benefits. A Space Station will add significantly to knowledge of our own planet and the universe we live in. A Space Station will stimulate technology resulting in "spinoffs" that improve the quality of life for people everywhere. A Space Station will create jobs and maintain our nation's skilled industrial base. A Space Station will improve our country's competitive stance at a time when more and more high technology products are being purchased overseas. And a Space Station will be a source of pride for all Americans and a visible symbol of our nation's ability to carry out complex scientific and engineering endeavors.

What is a Space Station?

The Space Station, as envisioned by NASA, will be a permanent, multi-purpose facility in orbit. It will serve as a laboratory to conduct basic research, an observatory to look down at the Earth or peer out into the sky, a garage to fix and service other spacecraft, a manufacturing plant to make exotic metal alloys, super-pure pharmaceuticals or perfect crystals, an assembly plant to build structures too large to fit in the Shuttle's cargo bay, and a storage warehouse to keep spare parts or even entire replacement satellites.

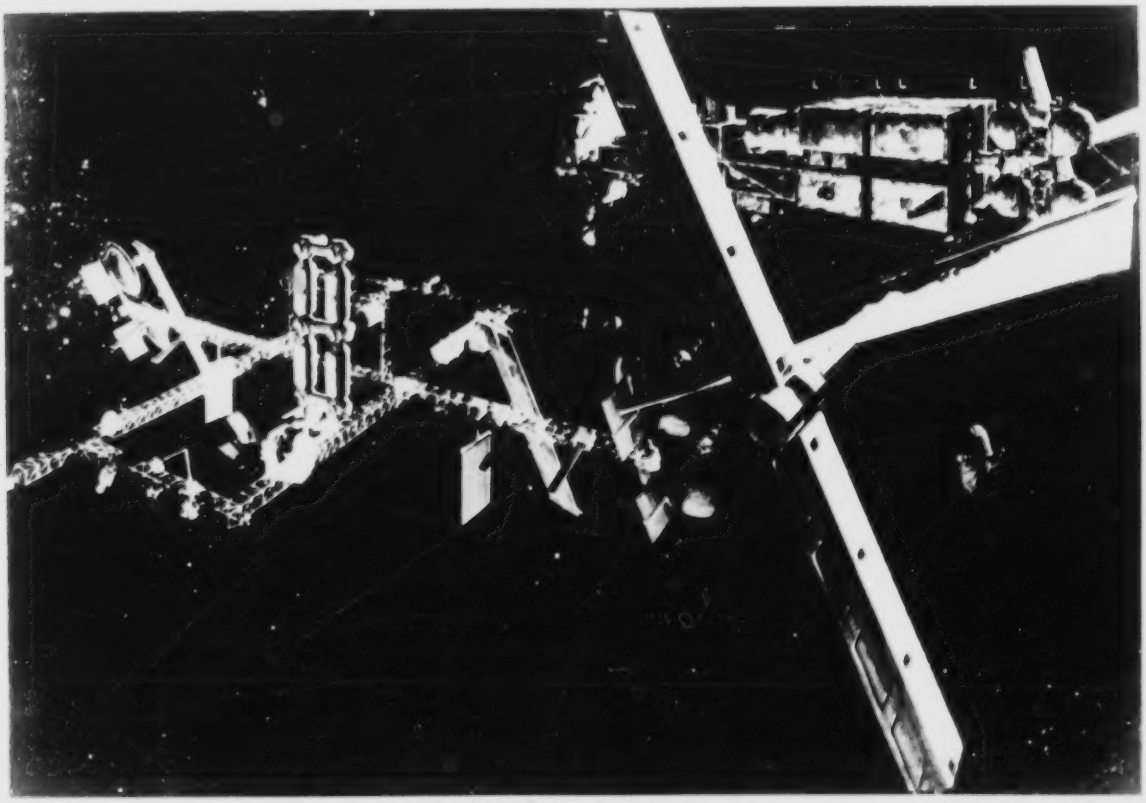
The Space Station concept provides for both manned and unmanned elements. The manned facility, as well as an unmanned free-flying platform, will be placed in a low Earth orbit of about 500 kilometers (315 miles) at an inclination to the equator of 28.5 degrees. Two or more platforms in high inclination or polar orbits will be launched and serviced by the Space Shuttle.

Identical pressurized modules, 13.6 meters (nearly 45 feet) long and approximately 5 meters (15 feet) in diameter, will be outfitted internally to serve either as a laboratory or as living quarters for Space Station crews. The initial Station will support a crew of eight people with crew rotation and resupply from the Space Shuttle at approximately three-month intervals. In addition to living quarters, the facility will provide utilities (electrical power, thermal control, attitude control and data processing), work space, and a docking hub to allow tending by the Space Shuttle. The modules will be able to support scientific research and technology development requiring crew interaction.

The unmanned platforms will be able to provide changeable payload accommodations for activities requiring minimum disturbance and protection from contamination. A maximum of common subsystems such as power, thermal, docking, data, etc., will be used both on the Space Station and the platforms. The co-orbiting platform will be tended and serviced from the Space Station.

The NASA/Industry Team

The idea of a Space Station has been under consideration for years. NASA has conducted preliminary plan-



Artist's rendering of NASA's Space Station of the mid-1990s illustrates dual keel configuration with pressurized living quarters and laboratories clustered together at the center. A free flying platform is being towed to the Space Station by an orbital maneuvering vehicle.

ning efforts over the past few years seeking the best Space Station concept to satisfy the requirements of potential users. On September 14, 1984, NASA issued a Request for Proposal (RFP) to U.S. industry for preliminary design and definition of the Space Station. The RFP solicited proposals on four separate work packages covering Space Station elements.

On April 19, 1985, NASA let competing contracts on each of the work packages. The work packages, NASA centers and contractors responsible are:

Work Package One. Marshall Space Flight Center, Huntsville, AL—definition and preliminary design of pressurized common modules, node structures, environmental control systems, laboratory module outfitting, logistics modules, engine elements within the propulsion system, and Orbital Maneuvering Vehicles (OMV) and Orbital Transfer Vehicle (OTV) accommodations. Contracts were awarded to Boeing Aerospace Co., Seattle, WA, and to Martin Marietta Aerospace, Denver, CO.

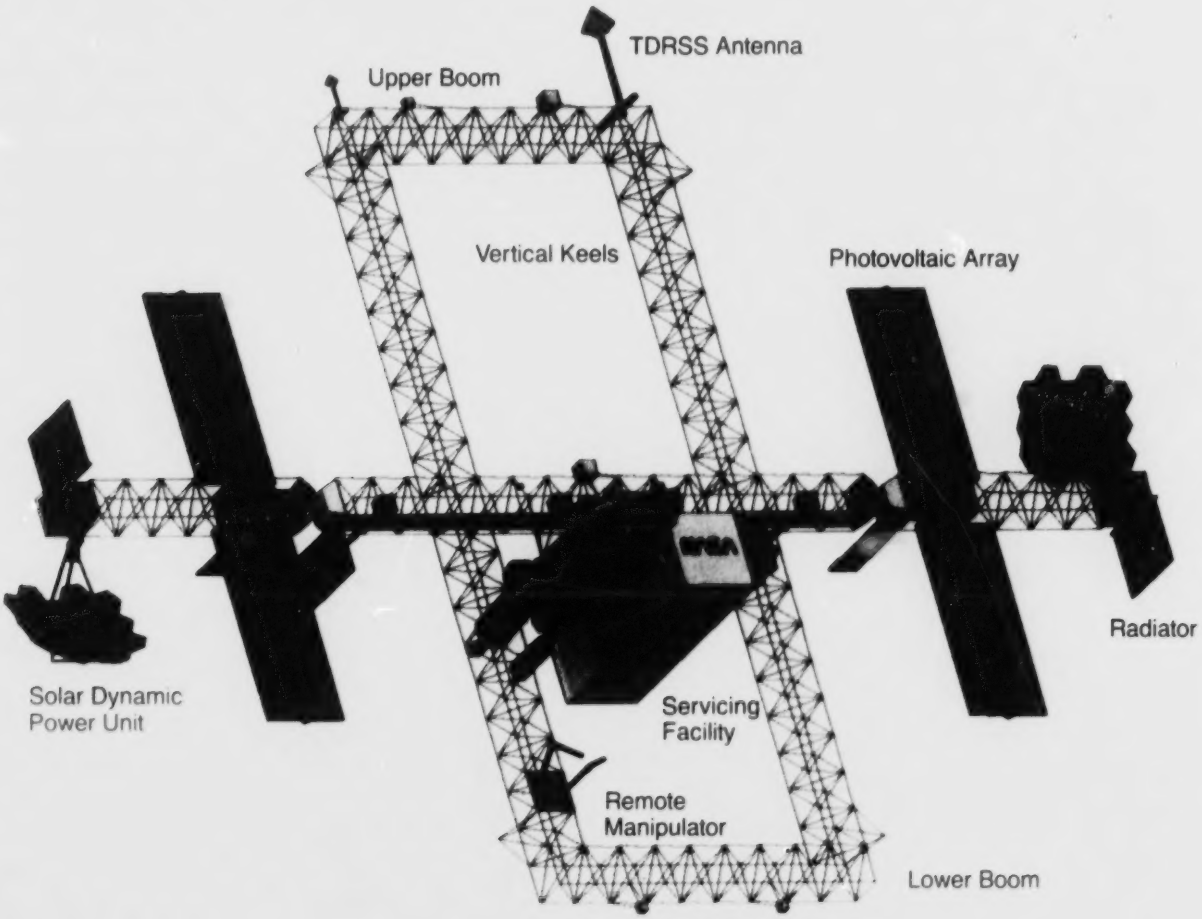
Work Package Two. Johnson Space Center, Houston, TX—definition and preliminary design of the structural framework to attach the various elements of the Space Station, to be attached mounted systems within the habitable modules, interfaces between the Space Station and the [illegible] Program, such as Remote Manipulator System, MMU, [illegible], pressurized gas storage, [illegible] management subsystems, airlocks and extravehicular activity (EVA) accommodations. Contracts were awarded to McDonnell Douglas Astronautics Co., Huntington Beach, CA, and to Rockwell International, Space Station Systems Division, Downey, CA.

Work Package Three. Goddard Space Flight Center, Greenbelt, MD—definition and preliminary design of the automated free-flying platforms and NASA's role in the development of provisions to service, maintain and repair the platforms and other free-flying spacecraft; flight teleoperator system; and provisions for instruments and payloads to be attached externally to the Space Station. Contracts were awarded to RCA Astro Electronics, Princeton, NJ, and to General Electric Co., Space Systems Division, Philadelphia, PA.

Work Package Four. Lewis Research Center, Cleveland, OH—definition and preliminary design of the electrical power generating, conditioning and storage systems. Contracts were awarded to Rocketdyne Division, Rockwell International, Canoga Park, CA, and to TRW Federal Systems Division, Redondo Beach, CA. NASA has since terminated TRW's participation in work package 4.

The Kennedy Space Center, FL, will be responsible for preflight and launch operations and will be involved in operations support activities. Other NASA centers will support the definition and preliminary design activities.

Dual Keel
Final Assembly Configuration



Shaping the Space Station

NASA is conducting a 21-month "Phase B" definition and preliminary design study during which Space Station designers will identify and evaluate alternative systems, components and philosophies resulting in a Space Station configuration that is responsive to the needs of potential Space Station users, cost-effective to operate and maintain, and flexible in terms of eventual growth in size and capabilities.

A configuration, called the "power tower" because of its single 122-meter (400-foot) tall spine, was used as the early reference.

Initial Space Station definition activities were completed in March 1986 at which time, based upon user requirements and detailed engineering analysis, NASA selected a modified version of the power tower, called the "dual keel" as the baseline configuration. The dual keel Space Station is rectangular in shape and features two parallel 90-meter (297-foot) tall vertical keels, crossed by a single horizontal beam which supports the solar-powered energy system. The pressurized modules have been placed near the Space Station's center of gravity, the most advantageous spot on the Station for conducting experiments that require a micro-gravity environment. The new configuration provides more space for attaching payloads, and more easily accommodates future growth of the Station.

To provide easy access and maximum privacy, the modules are arranged in a raft pattern, connected by external nodes which will house many of the distributed subsystems used to command and control the Station. External airlocks free up space inside for locating equipment and working space. The atmosphere inside the modules will be nearly identical to Earth's so that scientists interested in the effects of weightlessness on the human body can compare data acquired from earth-based testing against data gathered in space.

An environmental control and life support system will provide the crew with a breathable atmosphere, supply water for drinking, bathing and food preparation, remove

contaminants from the air and process biological wastes. The ECLSS system will be "closed" to permit oxygen to be recovered from the carbon dioxide expelled by the crew, and allow wash water, urine and condensate to be reused. Only food and nitrogen will have to be periodically resupplied.

Contractors will spend the remainder of the Phase B period performing preliminary design of the Space Station elements and subsystems. At the end of this period NASA expects to have a firm and responsive Space Station design and be in a position to proceed toward hardware development.

Competitive contracts for hardware development are scheduled for award in 1987. NASA's plans call for the Space Station to be assembled in orbit beginning in 1993 and to have a permanent manned capability in 1994. The Space Station will be launched in segments in the Shuttle orbiter's cargo bay and assembled in orbit. It will be capable of growth both in size and capability and is intended to operate for several decades.

International Participation in the Space Station

In keeping with a long term policy of international cooperation in space, and the President's invitation to U.S. friends and allies to participate in development of the Space Station, NASA has signed agreements with Canada, the European Space Agency and with Japan that provide a framework for cooperation during the definition and preliminary design activity.

Canada is performing preliminary design on a Mobile Servicing Center, which would be a multi-purpose structure equipped with manipulator arms that would be used to help assemble and maintain the Space Station, as well as help upkeep instruments and experiments mounted on the Station's framework.

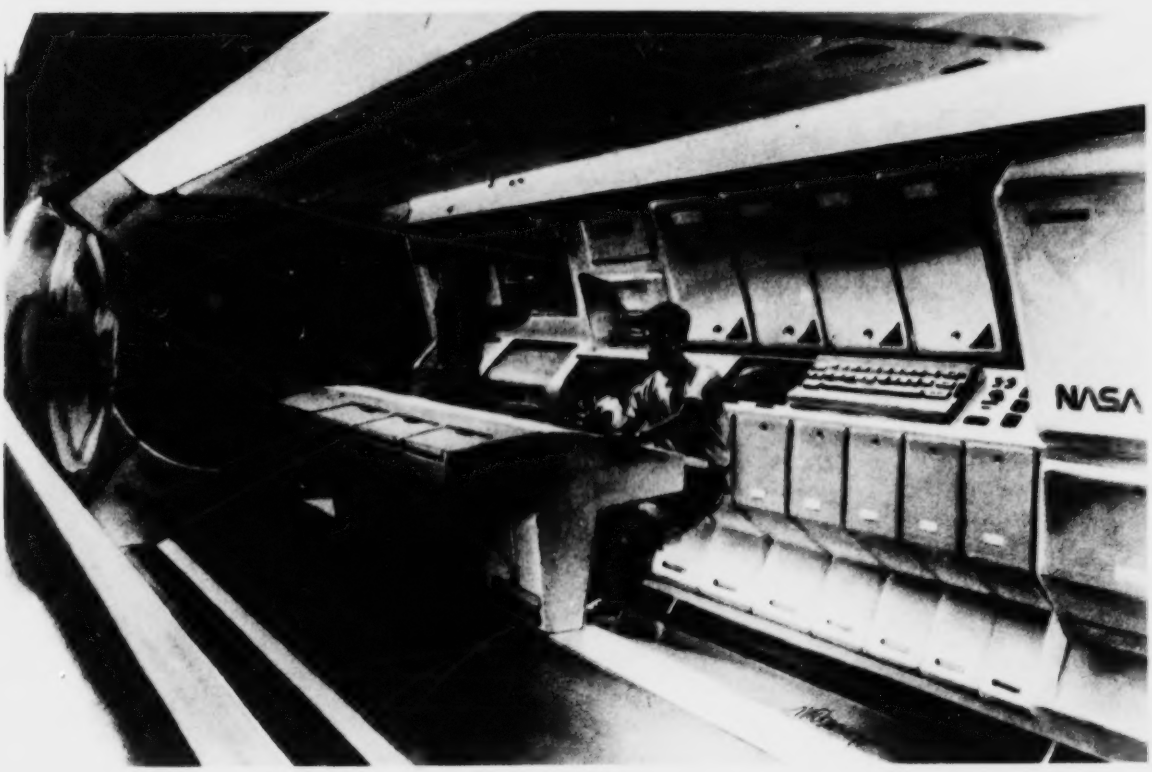
Japan is conducting preliminary design on an attached multi-purpose research and development laboratory that will provide a shirtsleeve environment work space for Station crews. The Japanese experiment module will also include an exposed work deck, a scientific/equipment airlock, a local remote manipulator arm and an experiment logistics module.

ESA is doing preliminary design work on a permanently-attached pressurized laboratory module and a polar-orbiting platform.

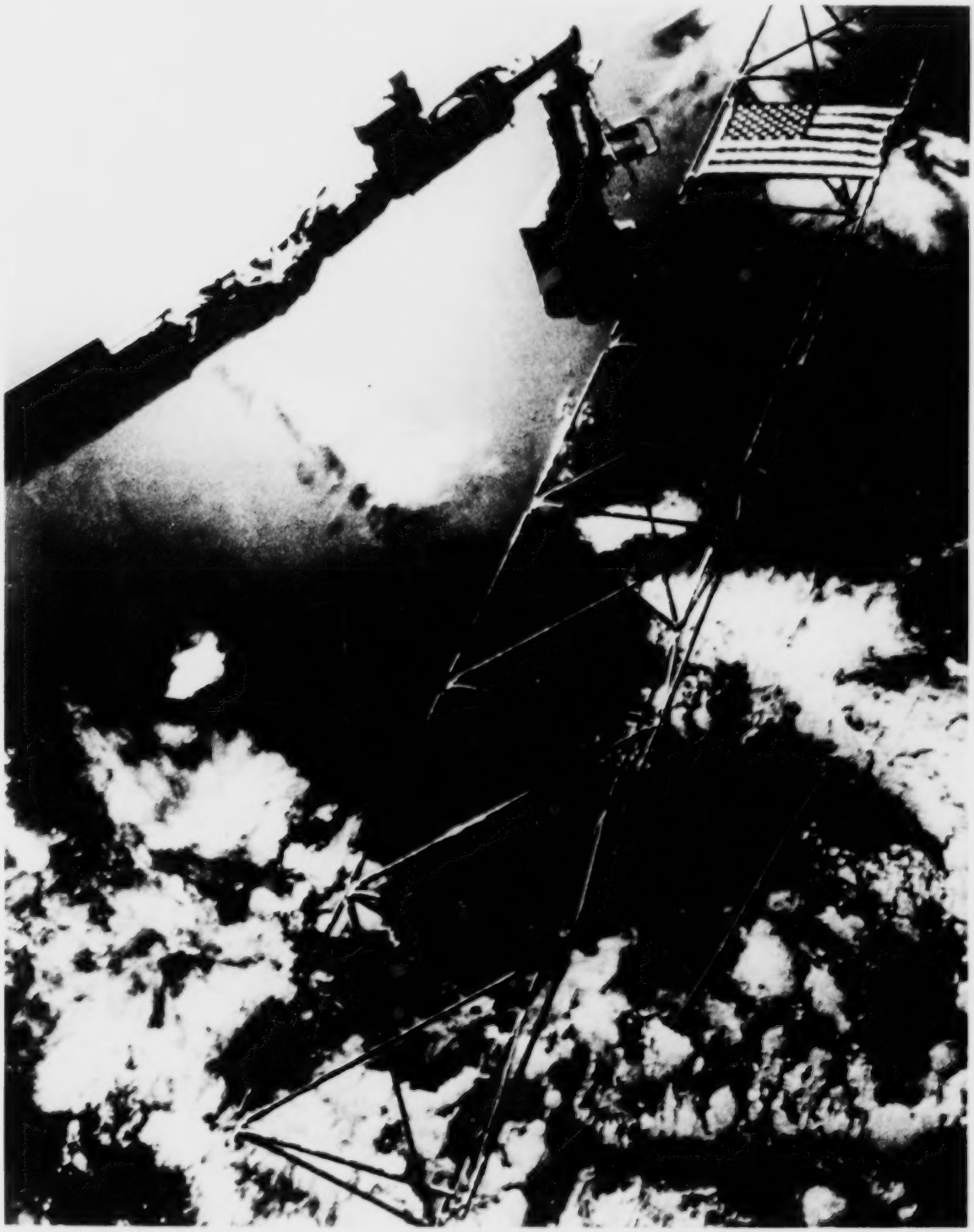
Cooperation during the development, operations and utilization phases will require separate agreements.

Advanced Technologies

Space Station has an extensive technology development program underway to provide technical options that are both reliable and cost effective for the Space Station program. Among the technologies which have the highest priority and the greatest potential for increasing the



This artist's concept shows what the interior of one habitation module might look like. A fully-equipped galley and facilities for group dining are envisioned for what will be the Space Station equivalent of a wardroom.



NASA Astronaut Sherwood "Woody" Spring checks joints on a tower that was assembled by Space Shuttle crewmen to demonstrate space construction techniques. Using NASA's Space Station as a base, astronauts will be able to assemble large structures.

McDonnell Douglas Payload Specialist Charles Walker processes a pharmaceutical product aboard the Space Shuttle using a device developed to be employed in commercial space manufacturing in the future. Pharmaceuticals are expected to be one of many commercial activities that will be supported by the Space Station.

productivity of the Station are data management, environmental control and life support, thermal control and power.

In designing the Space Station, contractors are paying particular attention to the recommendations of the NASA Advanced Technology Advisory Committee which is identifying automation and robotic technologies that could be used in the Space Station. Funds have been earmarked for research in automation and robotics. Before the first launch of Space Station elements aboard the Shuttle, NASA will have ready a flight telerobotic system that could be attached to a mobile remote manipulator to aid in assembling and maintaining the Space Station. The telerobotic system will also be used as a "smart" front end on an Orbital Maneuvering Vehicle for remote operations and servicing of free-flying payloads.

Space Station Commercial Capabilities

The Space Station will stimulate extensive commercial use of space by providing capabilities that are not now available to the private sector. These capabilities are possible because the Space Station will couple manned presence with unlimited stay-time in orbit with advanced automated systems.

The Space Station may in time enable the commercial production, in quantity, of critical materials not obtainable on Earth, such as extremely pure pharmaceuticals. Frequent crew intervention is required in the development phases for such production processes. The Space Station also will provide changeable payload accommodations for commercial remote sensing instruments.

NASA has signed a Memorandum of Understanding with Space Industries Inc., of Houston, TX, a privately-funded venture, to exchange information during the Phase B period. SII plans to develop a pressurized laboratory that would be launched by the Shuttle. Eventually, it could be serviced from the Space Station.

Tending, Servicing, Repairing Satellites, Platforms

The Space Station will serve as a permanent base for the efficient tending, servicing and repair of unmanned platforms and satellites, thereby increasing the lifetime of these expensive space assets and offering the flexibility to upgrade space systems as technology advances. This efficiency derives in part from the fact that the servicing equipment is stored on the Space Station and will not have to be brought up on the Space Shuttle for each individual servicing mission. The Space Station also will enable the in-orbit assembly and check-out of large space structures such as antennas, apertures, telescopes and satellites prior to their deployment.

Science and the Space Station

The Space Station will provide the capability to conduct space-based scientific research in fields such as astrophysics, solar system exploration, earth science and applications, life sciences, materials processing and communications.

NASA has established an advisory committee to evaluate the role the Station will play in future scientific tasks. Equivalent international advisory bodies exchange information on their activities and plans with respect to the Space Station.

Stepping Stone to the Future

Space Station research focused on extending human stay-time in space will contribute to future manned exploration and exploitation of space. Thus, the Space Station could provide the necessary first step for major future manned missions in space, such as a permanent lunar base, a manned mission to Mars, a manned survey of the asteroids, a manned scientific and communications facility in geosynchronous orbit, and a complex of advanced scientific and commercial facilities in low Earth orbit. Also, the Space Station could enable the staging of future unmanned missions, such as planetary probes including the possibility of sample returns.

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NASA Space Station

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NASA
National Aeronautics and
Space Administration

Information Summaries

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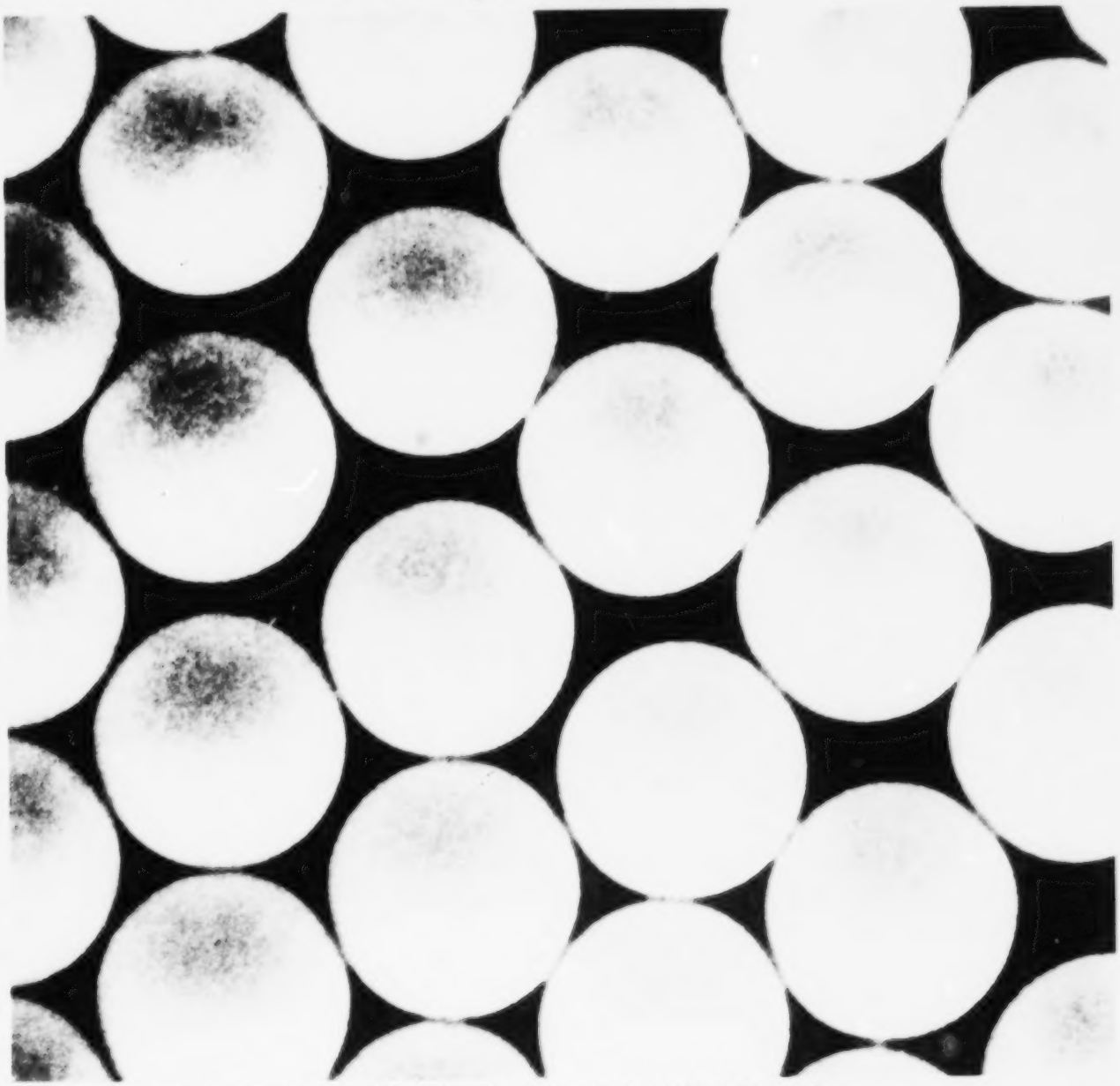
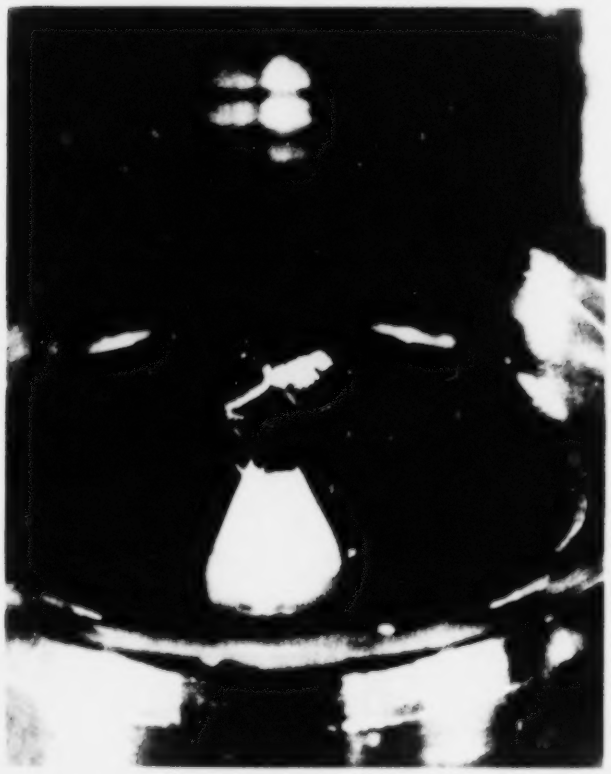
Materials Processing in Space



The first consumer product "made in space" is a microsphere so small it is invisible to the naked eye.



This crystal grown aboard SpaceLab 3 and similar experiments could lead to major advances in electronics and industry.

Materials processing is the science by which ordinary and comparatively inexpensive raw materials are made into useful crystals, chemicals, metals, ceramics, and countless other manufactured products. With it, we can build modern computers and communications systems, turbines for aircraft, and electric power plants. Materials processing makes it possible for us to produce chemical and biological compounds for use in medicine, and high-strength alloys and heat resistant ceramic tiles for use in the space program.

Materials processing on Earth took us into the Space Age and the near-weightless environment of Earth orbit. There, the extended benefits of working in weightlessness have opened new and unique opportunities for the science of materials processing. In the microgravity environment of an orbiting spacecraft, scientists can use procedures that are all but impossible on Earth.

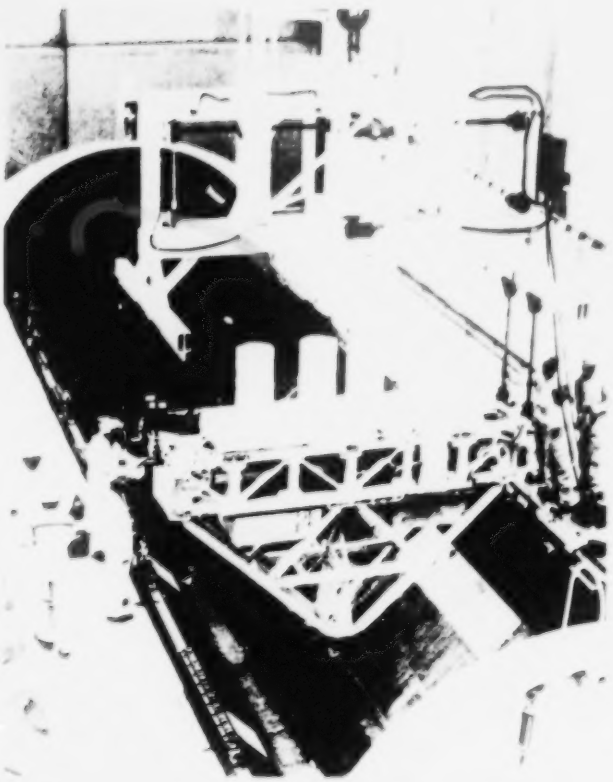
In orbit, materials processing can be accomplished without the effects of gravity, which on Earth causes materials of different densities and temperatures to separate and deform under the influence of their own masses. However, when we refer to an object as "weightless," we do not strictly mean there is an absence of gravity. Rather we are referring to the absence of relative motion between objects in a freely falling environment.

For example, if a man standing in an elevator drops a coin, the coin falls to the floor. But if the elevator cable breaks and the elevator begins to fall, a dropped coin will literally float. The coin will float (relative to the man and the elevator) because the elevator and everything within it will be in a state of free-fall. This principle of free-fall is used to obtain weightlessness on the ground (in drop towers and drop tubes), in the air (aboard research aircraft), and in orbit (aboard the Space Shuttle).

Drop towers and airplanes provide weightlessness for up to 40 seconds, but extended periods of weightlessness can only be achieved on an orbiting spacecraft such as the Space Shuttle, the Space Station, or a privately owned free-flying platform. Moreover, the weightlessness that is achieved by a spacecraft is not caused by an absence of gravity, but by the effect the spacecraft's orbiting speed has in countering the effects of gravity. Without gravity, the spacecraft would not follow a circular orbit, but would shoot off like a stone from a slingshot.

Types of Experiment Payloads

At present, NASA's Space Shuttle is one of the principal means for conducting orbital research. Experiments aboard the Shuttle may be conducted in the mid-deck area of the crew cabin, in the cargo bay, using either the Materials Experiment Assembly (MEA) or the Materials Science Laboratory (MSL), and in the Spacelab module. Each Shuttle payload area offers certain special characteristics.



A Materials Science Lab (MSL) is lowered into the cargo bay where it will be anchored and connected to Shuttle resources for carrying out experiments in orbit.

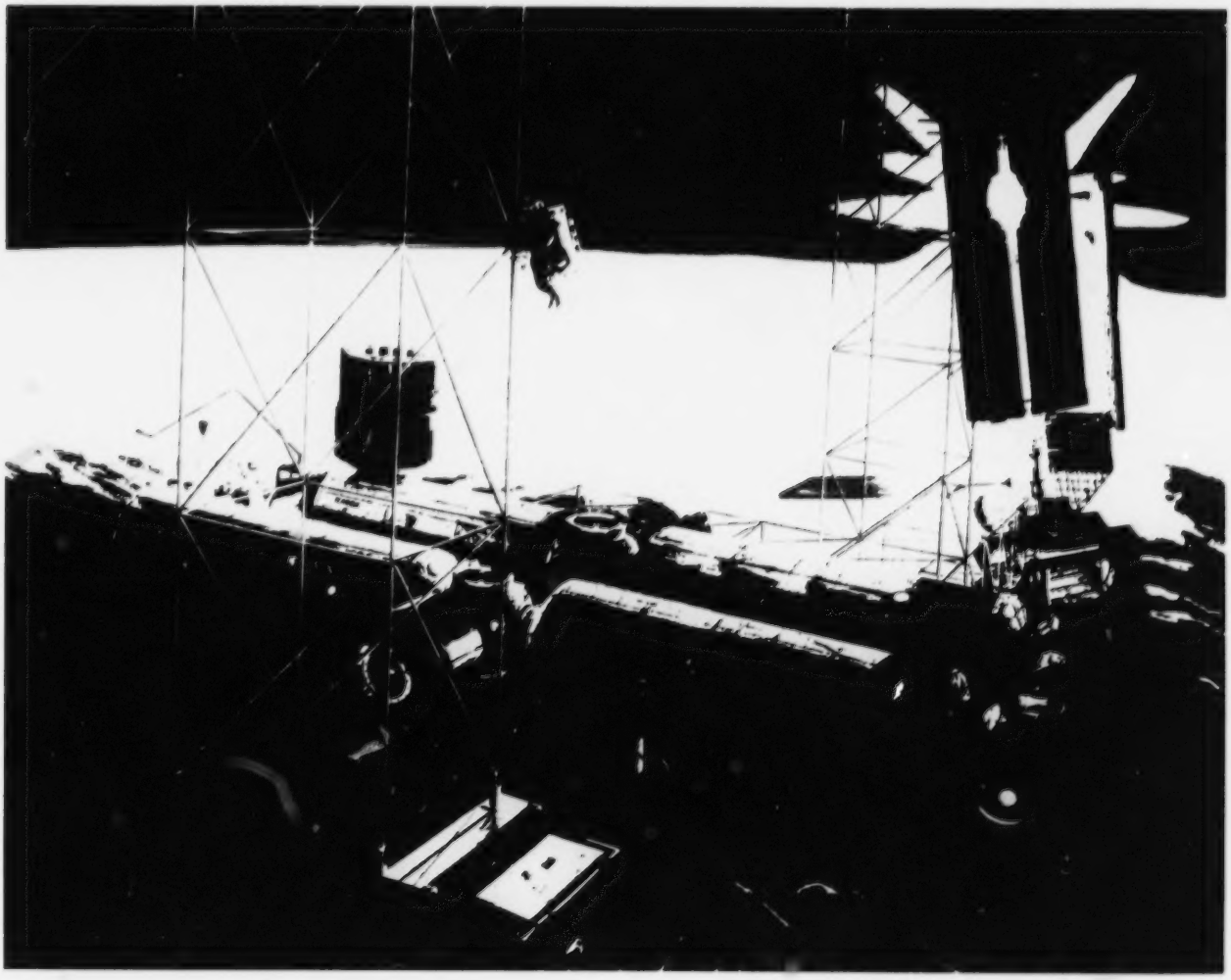
Mid-deck Payloads. Materials processing experiments can be carried in one or more of the 42 mid-deck storage lockers. These lockers are about .05 cubic meters (2 cu ft) in size and can hold experiments weighing up to 27 kilograms (60 lb). Shuttle crews can conduct the experiments inside the crew cabin.

Cargo Bay Payloads. Experiments carried in the cargo bay use either the Materials Experiment Assembly (MEA) or the Materials Science Laboratory (MSL). Payloads using the MEA are self-contained and operate independently of the Shuttle's power and other resources. Experiments on the MSL use the resources provided by the Orbiter, and on a single flight can be as large as .33 cubic meters (12 cu ft) and as heavy as 950 kilograms (2,100 lb).

Spacelab Payloads. Experiments conducted on Spacelab are similar to MSL experiments, except that the crew can be more involved. As Spacelab missions evolve, it is expected that each will be dedicated to a specific scientific discipline, such as life sciences, environmental observations, or materials processing. Such an arrangement will reduce flight costs and integration requirements, and will permit increased coordination among experimenters.

Recent Accomplishments

NASA's Commercial Use of Space program seeks to use the weightlessness achieved in space to better understand physical phenomena and to control materials processes. NASA's strategy in this program is to work upward from ground-based research (drop towers and drop tubes) to air and suborbital research (aircraft and sounding rockets) to orbital research (the Space Shuttle and Space Station). NASA also involves the academic and industrial communities in flight experiments aimed at understanding processes on Earth and at developing processes uniquely suited to the microgravity of space. Accomplishments have ranged from theoretical investigations to large experiments aboard the Space Shuttle.



Artist's concept of Space Station. While the Station is permanently in orbit, products from it will benefit Earth by providing inhabitants with new materials, medicines, computers, and communications.

Vapor growth of compound-type and alloy-type crystals. Crystals of compounds and alloys have been grown by chemical vapor transport. Practical applications of this experiment could improve semiconductor technology for the electronics industry.

Containerless processing of glass. Glass samples have been injected into a furnace, positioned by acoustic pressure, melted, and cooled. This containerless processing method can be used to better understand glass formation and to improve glass for optical and electrical applications.

Miscibility-gap materials. Immiscible metals have been alloyed with the desired distribution of constituents and studied. An immiscible alloy is a mixture that separates rapidly under the effects of gravity. Before the molten metals solidify, density differences cause the less dense metal to float on the denser metal. The miscibility problem for metals is very much like trying to mix oil and water. However, in the microgravity of space, the ability to mix such metals may lead to improved structural, electrical, and magnetic materials.

Continuous flow electrophoresis. NASA plans continued space-based research to refine and improve biological separation techniques for potential applications. A recent commercial experiment, the McDonnell Douglas continuous flow electrophoresis, is being watched closely by researchers. The experiment offers the potential for commercial production in space of biological materials, such as pharmaceuticals.

Growth of precision latex spheres. Experiments have demonstrated that weightless processing produces better formed and more uniformly sized microspheres. These small, uniform latex spheres are in demand on Earth for use in calibrating electron microscopes, particle counters, and aerosol monitoring devices. The National Bureau of Standards has made 10-micron sized spheres available as calibration standards in their Standard Reference Material Program. This makes the beads produced by these experiments the first product sold that was "made in space."

The Future of Microgravity Processing

Over the next 15 years, space-based research will stress both scientific and commercial goals. Products will include crystals, metals, ceramics, glasses, and biological materials. Processes will include containerless processing and fluid and chemical transport. As research in these areas develops, the benefits will become increasingly apparent on Earth: new materials, more efficient use of fuel resources, new pharmaceuticals, advanced computers and lasers, and better communications. Like space, the opportunities offered by microgravity science and applications are vast and are only beginning to be explored. The NASA program will evolve over the next decade to take maximum advantage of our planned Space Station capability.

Payload Specialist Dr. Byron Lichtenberg studies the behavior of fluid in microgravity. Lichtenberg uses the fluid physics module in the Materials Science Double Rack.

NASA
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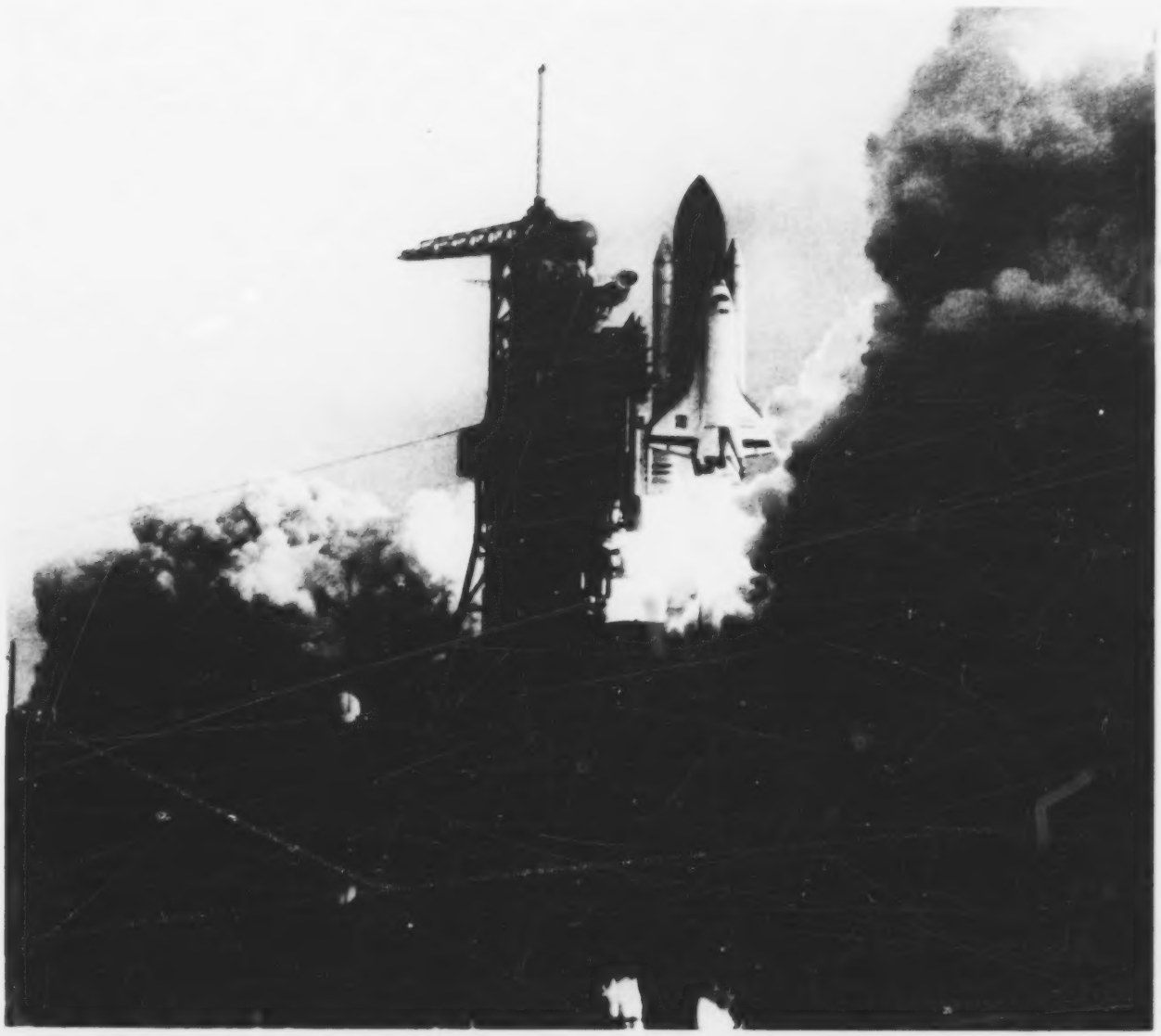
Information Summaries

PMS 018 (KSC)
March 1987

Countdown!

NASA Launch Vehicles and Facilities



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Space Launch Vehicles

People and cargo are propelled into space by rocket power. NASA uses two types of rockets for these purposes – manned and unmanned. The latter, often referred to as expendable launch vehicles, have one or more powered stages. The manned Space Shuttle, the key element of the nation's Space Transportation System, or STS, is a unique design, and is in a class by itself.

Payload weight, destination and purpose determine what vehicle capabilities are required for each mission. A low-weight spacecraft designed to operate in near-Earth orbit might be flown aboard NASA's smallest space vehicle, the Scout. Sending a manned Apollo spacecraft to the Moon required the massive Saturn V. The powerful Titan-Centaur combination sent large and complex unmanned scientific explorers such as the Vikings and Voyagers to examine other planets. Atlas-Agenas sent several spacecraft to impact the Moon. Atlas-Centaurs and Deltas have launched over 200 spacecraft for a wide variety of applications that cover the broad range of the national space program.

Today, NASA's fleet of space launch vehicles include only the unmanned Scout, Delta and Atlas-Centaur, and the manned Space Shuttle.

Inactive Launch Vehicles

Atlas/Agena

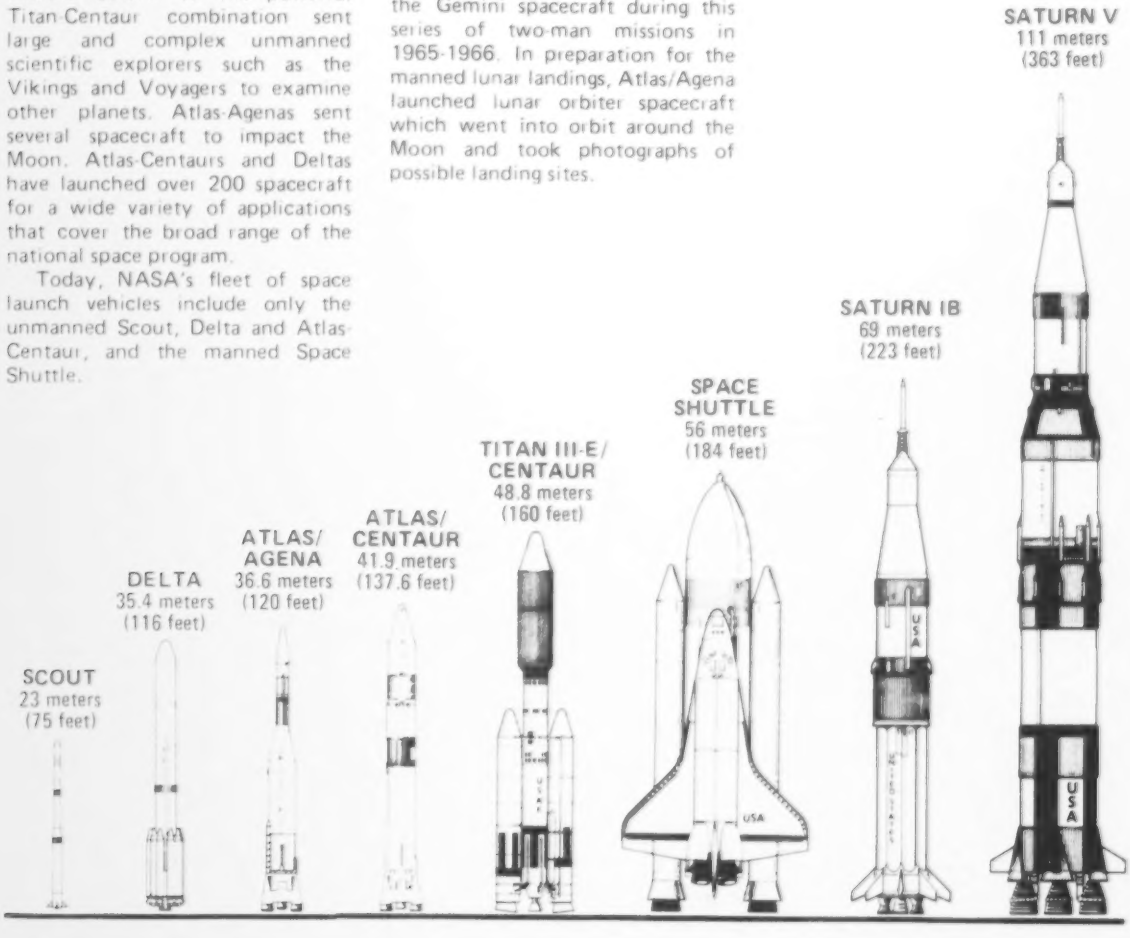
The Atlas/Agena was a multi-purpose two-stage liquid propellant rocket. It was used to place unmanned spacecraft in Earth orbit, or inject them into the proper trajectories for planetary or deep space probes.

The programs in which the versatile Atlas/Agena was utilized included early Mariner probes to Mars and Venus, Ranger photographic missions to the Moon, the Orbiting Astronomical Observatory (OAO), and early Applications Technology Satellites (ATS). The Agena upper stage also was used as the rendezvous target vehicle for the Gemini spacecraft during this series of two-man missions in 1965-1966. In preparation for the manned lunar landings, Atlas/Agena launched lunar orbiter spacecraft which went into orbit around the Moon and took photographs of possible landing sites.

The Atlas/Agena stood 36.6 meters (120 feet) high, and developed a total thrust at liftoff of approximately 1,725,824 newtons (288,000 pounds). It was last used in 1968 to launch an Orbiting Geophysical Observatory (OGO).

Saturn V

The Saturn V, America's most powerful staged rocket, carried out the ambitious task of sending astronauts to the Moon. The first Saturn V vehicle, Apollo 4, was launched on November 9, 1967. Apollo 8, the first manned flight of the Saturn V, was also the first manned flight to the Moon; launched in December 1968, it



orbited the Moon but did not land. Apollo 11, launched on a Saturn V on July 16, 1969, achieved the first lunar landing.

Saturn V began its last manned mission on December 7, 1972, when it sent Apollo 17 on the final lunar exploration flight. It was last used on May 14, 1973, when it lifted the unmanned Skylab space station into Earth orbit, where it was occupied by three crews for a 171 days.

All three stages of the Saturn V used liquid oxygen as the oxidizer. The first stage burned kerosene with the oxygen, while the fuel for the two upper stages was liquid hydrogen. Saturn V, with the Apollo spacecraft and its small emergency escape rocket on top, stood 111 meters (363 feet) tall, and developed 34.5 million newtons (7.75 million pounds) of thrust at liftoff.

Saturn IB

The Saturn IB was originally used to launch Apollo lunar spacecraft into Earth orbit, to train for manned flights to the Moon. The first launch of a Saturn IB with an unmanned Apollo spacecraft took place in February 1966. A Saturn IB launched the first manned Apollo flight, Apollo 7, on October 11, 1968.

After the completion of the Apollo program, the Saturn IB launched three missions to man the Skylab space station in 1973. In 1975 it launched the American crew for the Apollo/Soyuz Test Project, the joint U.S./Soviet Union docking mission.

Saturn IB was 69 meters (223 feet) tall with the Apollo spacecraft and developed 7.1 million newtons (1.6 million pounds) of thrust at liftoff.

Titan III-E/Centaur

The Titan III-E/Centaur, first launched in 1974, had an overall height of 48.8 meters (160 feet). Designed to use the best features of three proven rocket propulsion systems, this vehicle gave the U.S. an extremely powerful and versatile rocket for launching large spacecraft on planetary missions.

The Titan III-E/Centaur was the launch vehicle for two Viking spacecraft to Mars, and two Voyager spacecraft to Jupiter, Saturn and Uranus. It also launched two Helios spacecraft toward the Sun. All provided remarkable new information about our solar system. The Vikings and Voyagers produced spectacular color photograph of the planets they explored.

The Titan III-E booster was a two-stage liquid-fueled rocket with two large solid-propellant rockets attached. At liftoff, the solid rockets provided 10.7 million newtons (2.4 million pounds) of thrust.

The Centaur stage, still in use today, produces 133,440 newtons (30,000 pounds) of thrust from two main engines, and burns for up to seven and one-half minutes. The Centaur can be restarted several times, which allows for more flexibility in launch times.

Current Launch Vehicles

Delta

Delta is called the workhorse of the space program. This vehicle has successfully transported over 160 scientific, weather, communications and applications satellites into space. These include the TIROS Nimbus and ITOS satellites, and many Explorer scientific spacecraft.

First launched in May, 1960, the Delta has been continuously upgraded over the years. Today it stands 35.4 meters (116 feet) tall. Its first stage is augmented by nine Caster IV strap-on solid propellant motors, six of which ignite at liftoff and three after the first six burn out 58 seconds into the flight. The average first-stage thrust with the main engines and six solid-propellant motors burning is 3,196,333 newtons (718,000 pounds). Delta has liquid-fueled first and second stages and a solid-propellant third stage. For most launches today, this third stage has been replaced by a Payload Assist Module (PAM) stage attached to the spacecraft.

The new PAM upper stage is also used on Space Shuttle launches. It boosts spacecraft from the low Earth orbit achieved by the Shuttle orbiter into higher ones. Many spacecraft, especially communications satellites, operate in a geosynchronous (geostationary) orbit some 35,792 kilometers (22,240 miles) above the equator. With the PAM and a recent change to a more powerful second stage, the Delta can lift some 1,270 kilograms (2,800 pounds) into a highly elliptical orbit, for transfer into geosynchronous orbit by a motor built into the spacecraft. This is almost double the 680 kilograms (1,500 pounds) a Delta could manage only seven years ago.

Atlas/Centaur

The Atlas/Centaur is NASA's standard launch vehicle for intermediate payloads. It is used for the launch of Earth orbital, geosynchronous, and interplanetary missions.

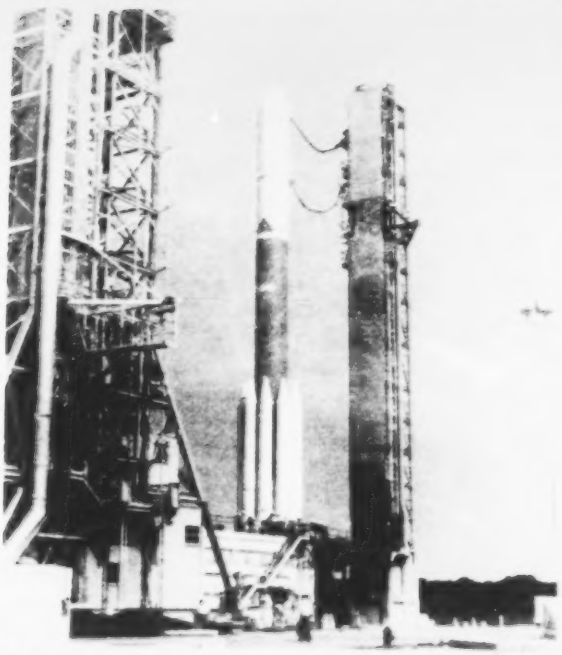
Centaur was the nation's first high-energy, liquid-hydrogen liquid-oxygen launch vehicle stage. It became operational in 1966 with the launch of Surveyor 1, the first U.S. spacecraft to soft-land on the Moon.

Since 1966, both the Atlas booster and the Centaur second stage have undergone many improvements. At present, the combined stages can place over 4,530 kilograms (10,000 pounds) in low-Earth orbit, about 2,020 kilograms (4,453 pounds) in geosynchronous transfer orbit, and over 1,000 kilograms (2,205 pounds) on an interplanetary trajectory.

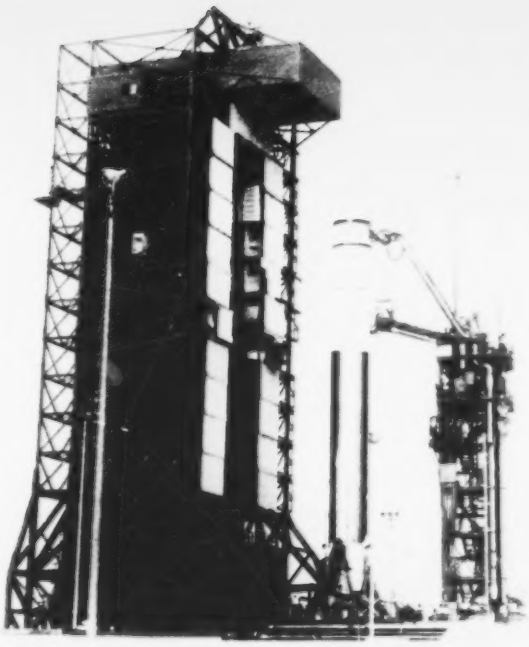
An Atlas-Centaur stands 41.9 meters (137.6 feet) tall. At liftoff, the Atlas booster develops over 1.9 million newtons (438,400 pounds) of thrust. The Centaur second stage develops 146,784 newtons (33,000 pounds) of thrust in a vacuum.

Spacecraft launched by Atlas/Centaurs include Orbiting Astronomical Observatories; Applications Technology Satellites; Intelsat IV, IV-A and V communications satellites; Mariner Mars orbiters; a Mariner spacecraft which made a fly-by of Venus and three of Mercury; Pioneer spacecraft which accomplished fly-bys of Jupiter and Saturn, and Pioneers that orbited Venus and plunged through its atmosphere to the surface.

Delta and Atlas-Centaur vehicles are assembled, checked out and tested at the launch pads. This contrasts with the mobile concept used for Space Shuttle operations at Complex 39.



Delta at Complex 17



Atlas-Centaur at Complex 36

Scout

The Scout launch vehicle, which became operational in 1960, has been undergoing systematic upgrading since 1976. The standard Scout vehicle is a solid-propellant, four-stage booster system approximately 23 meters (75 feet) in length with a launch weight of 21,600 kilograms (46,620 pounds) and liftoff thrust of 588,240 newtons (132,240 pounds).

Recent improvements include and uprated third-stage motor which increases the Scout's payload capability. It can now place up to 211 kilograms (465 pounds) in low Earth orbit. The third stage also has been provided with an improved guidance system.

Over 100 Scouts have been launched to date. They have been used to place a variety of U.S. and international payloads into inclined, equatorial and polar orbits for orbital, probe and lunitey missions.

Space Shuttle

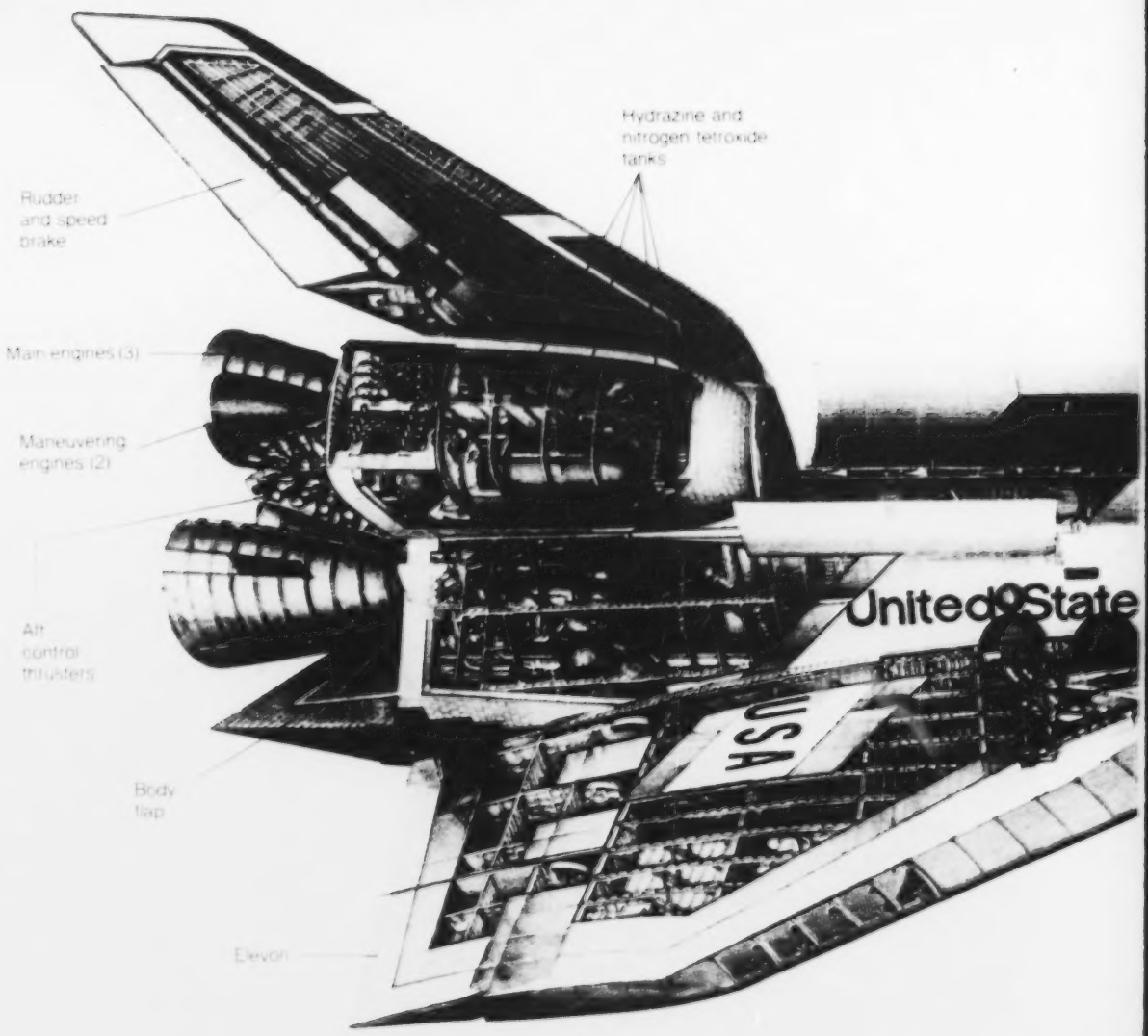
On April 12, 1981, the first Space Shuttle vehicle lifted off from Launch Complex 39, Pad A, at the Kennedy Space Center. After a two-day test flight mission that verified the craft's ability to function in space, the orbiter Columbia landed at Edwards Air Force Base in California. The Vehicle was piloted by astronauts John Young and Robert Crippen. The STS-1 mission marked the first time a new space vehicle had been manned on its first flight.

The Space Shuttle consists of a reusable delta-winged spaceplane called the orbiter, two solid propellant rocket boosters, which are recovered and also reused, and an expendable external tank, containing liquid propellants for the orbiter's three main engines.

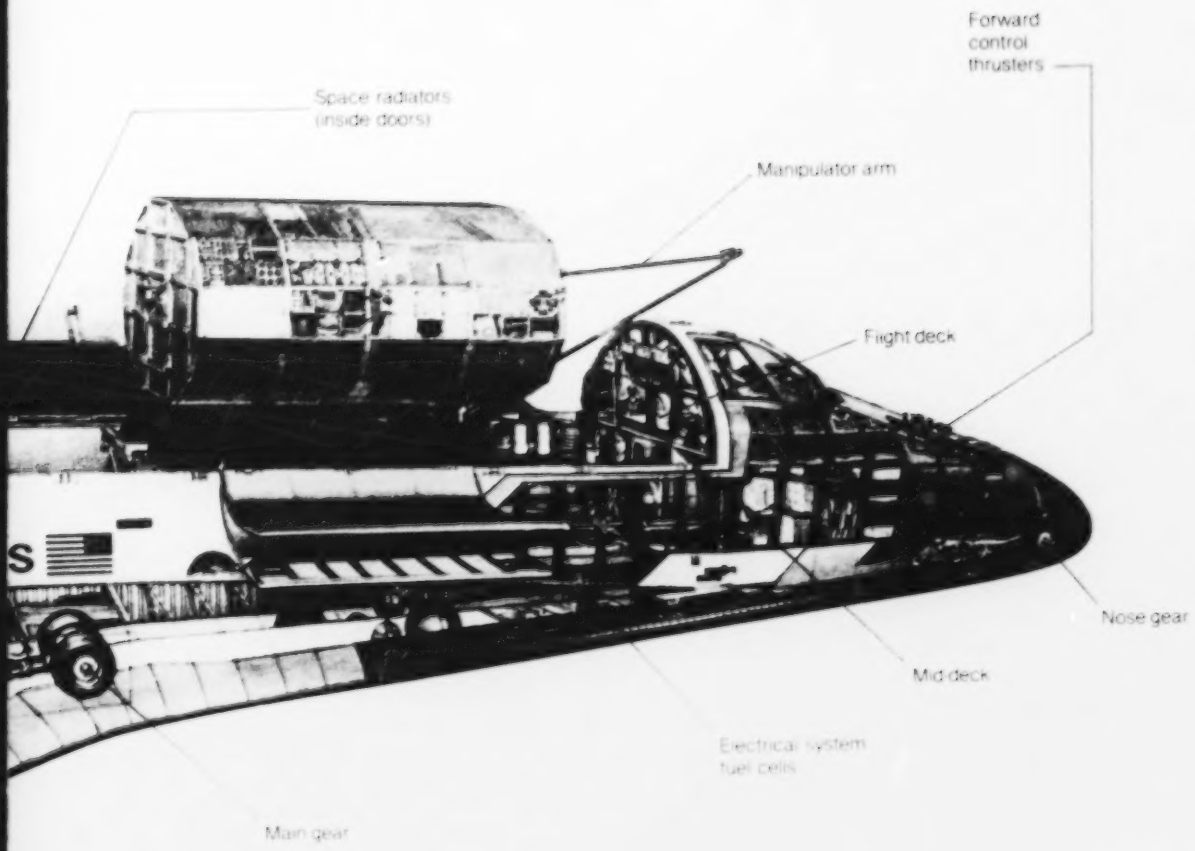
The assembled Space Shuttle is approximately 56 meters (184 feet) long, 23.3 meters (76 feet) high (to tip of orbiter's vertical tail) and 24 meters (78 feet) wide, measured across the orbiter's wing tips. Liftoff weight of the Shuttle vehicle is approximately 2,041,168 kilograms (4,500,000 pounds).

At launch, the orbiter's three liquid fueled engines, drawing propellants from the external tank — and the two solid propellant rocket boosters burn simultaneously. Together, they generate about 28,650,000 newtons (6,400,000 pounds) of thrust at liftoff. As the Space Shuttle reaches an altitude of about 50 kilometers (31 miles), the spent solids are detached and parachuted into the ocean where they are recovered by waiting ships for eventual refurbishment and reuse on later missions. The orbiter and external tank, still attached to each other, continue toward Earth orbit. When the orbiter's main engines cut off, just before orbit is achieved, the external tank is jettisoned, to impact in a remote ocean area. Using onboard orbital maneuvering engines, the orbiter with its crew and payload accelerates into orbit to carry out an operational mission, normally lasting from two to seven days.

When the mission is completed, the orbiter reenters the atmosphere and returns to Earth, gliding to an unpowered landing. Touchdown speed is above 335 kilometers (210 miles) per hour.


Hydrazine and nitrogen tetroxide tanks
Rudder and speed brake
Main engines (3)
Maneuvering engines (2)
Aft control thrusters
Body flap
Elevon
United States
USA

The Orbiter



Length: 37 Meters (122 feet)
Taxi Height: 17.4 meters (57 Feet)

Wing Span: 24 meters (78 Feet)
Landing Weight: (Variable – About 90,718 kilograms (200,000 pounds)

MAIN ENGINE THRUST: 1,668,000 newtons (375,000 pounds each at sea level)

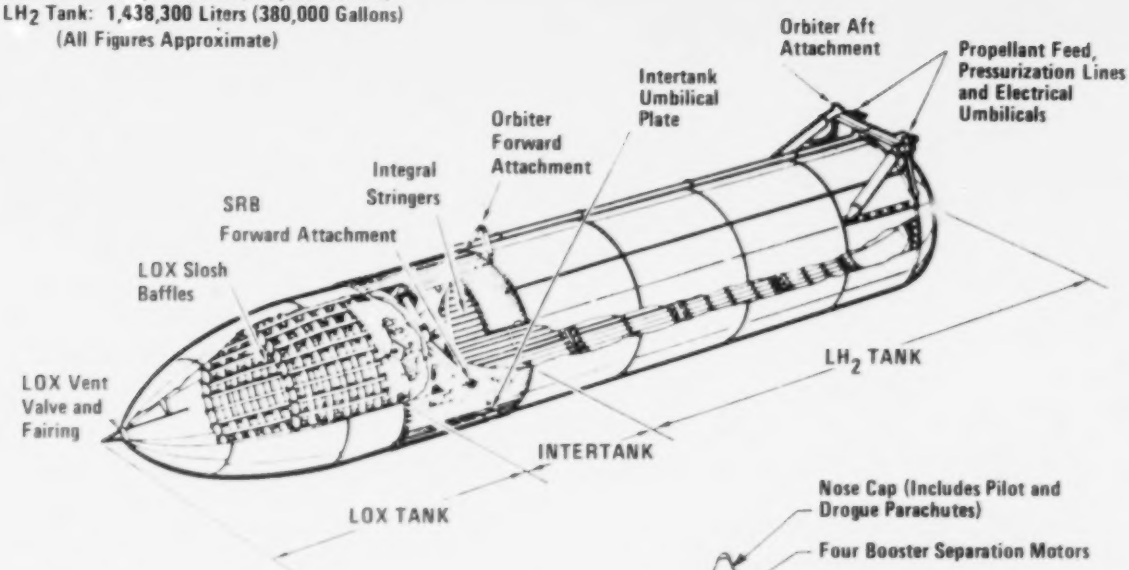
Cargo Bay: 18.3 meters (60 feet) along
4.6 meters (15 feet) wide

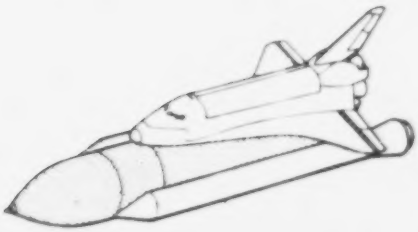
Payload Weight: 29,500 kilograms (65,000 pounds) up
14,515 kilograms (32,000 pounds) down

(All Figures Approximate)

External Tank

Length: 47 meters (154 feet)
Diameter: 8.4 meters (27.5 feet)
LOX Tank: 529,000 Liters (140,000 Gallons)
LH_2 Tank: 1,438,300 Liters (380,000 Gallons)
(All Figures Approximate)

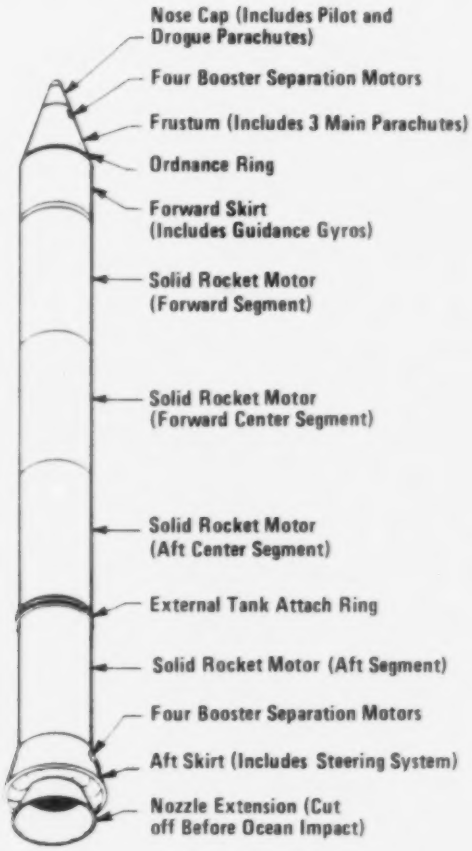




Solid Rocket Booster

Length: 45.4 meters (149.1 feet)
Diameter: 3.7 meters (12.2 feet)
Weight: 589,670 kilograms (1,300,000 pounds)
Thrust: 11,787,000 newtons (2,658,000 pounds)

(All Figures Approximate)


Nose Cap (Includes Pilot and Drogue Parachutes)
Four Booster Separation Motors
Frustum (Includes 3 Main Parachutes)
Ordnance Ring
Forward Skirt (Includes Guidance Gyros)
Solid Rocket Motor (Forward Segment)
Solid Rocket Motor (Forward Center Segment)
Solid Rocket Motor (Aft Center Segment)
External Tank Attach Ring
Solid Rocket Motor (Aft Segment)
Four Booster Separation Motors
Aft Skirt (Includes Steering System)
Nozzle Extension (Cut off Before Ocean Impact)

Propellants

Sir Isaac Newton stated in his Third Law of Motion that "every action is accompanied by an equal and opposite reaction." A rocket operates on this principle. The continuous ejection of a stream of hot gases in one direction causes a steady motion of the rocket in the opposite direction.

A jet aircraft operates on the same principle, using oxygen in the atmosphere to support combustion of its fuel. The rocket engine is designed to operate outside the atmosphere, and so must carry its own oxidizer.

The gauge of efficiency for rocket propellants is specific impulse, stated in seconds. The higher the number, the "hotter" the propellant.

Stated most simply, specific impulse is the period in seconds for which a one pound mass of propellant (total of fuel and oxidizer) will produce a thrust of one pound force. Although specific impulse is a characteristic of the propellant system, its exact value will vary to some extent with the operating conditions and design of the rocket engine. It is for this reason that different numbers are often quoted for a given propellant or combination of propellants.

NASA launch vehicles use four types of propellants: petroleum, cryogenics, hypergolics and solids.

Petroleum:

The petroleum used as a rocket fuel is a type of kerosene similar to the kind burned in heaters and lamps. However, that used for rocket fuel is highly refined, and is called RP–1 (Refined Petroleum). It is burned with liquid oxygen (the oxidizer) to provide thrust.

RP–1 is used as a fuel in the first stage boosters of the Delta and Atlas-Centaur rockets. It also was used to power the first stages of the Saturn IB and Saturn V. RP–1 delivers a specific impulse considerably less than cryogenic fuels.

Cryogenic:

Cryogenic propellants used are liquid oxygen (LOX), which serves as an oxidizer, and liquid hydrogen (LH2), which is a fuel. The word cryogenic is a derivative of the Greek kryos, meaning "ice cold." LOX remains in a liquid state at temperatures of –183 degrees Celsius (–298 degrees Fahrenheit); LH2 remains liquid at temperatures of –253 degrees Celsius (–423 degrees Fahrenheit).

In gaseous form, oxygen and hydrogen have such low densities that extremely large tanks would be required to store them aboard a rocket. But cooling and compressing them into liquids vastly increases their density, making it possible to store them in large quantities in smaller tanks.

The distressing tendency of cryogenics to return to gaseous form unless kept super-cool makes them difficult to store over long periods of time, and hence less than satisfactory as propellants for military rockets, which must be kept launch-ready for months at a time.

But the high efficiency of the liquid hydrogen/liquid oxygen combination makes the low temperature problem worth coping with when reaction time and storability are not too critical. Hydrogen has about 40 percent more "bounce to the ounce" than other rocket fuels, and is very light, weighing about one-half pound per gallon.

Oxygen is much heavier, weighing about 10 pounds per gallon.

The RL–10 engines used by Centaur, the United States' (and the world's) first liquid hydrogen rocket stage, have a specific impulse of 444 seconds. The J–2 engines used on the Saturn V second and third stages, and on the Saturn IB's second stage, also burned the LOX/LH2 combination. They had specific impulse ratings of 425 seconds.

For comparison purposes, the liquid oxygen/kerosene combination used in the cluster of five F–1 engines in the Saturn V first stage had specific impulse ratings of 260 seconds. The same propellant combination used by the booster stage of the Atlas-Centaur rocket yields 258 seconds in the booster engine and 220 seconds in the sustainer.

The high efficiency engines aboard the Space Shuttle orbiter use liquid hydrogen-oxygen and have a specific impulse rating of 455 seconds. The two liquid propellants also are used by the orbiter's fuel cells to produce electrical power through a process best described as electrolysis in reverse.

Liquid hydrogen and oxygen burn clean, leaving a by-product of water vapor.

The rewards for mastering LH2 are substantial. The ability to use hydrogen means that a given mission can be accomplished with a smaller quantity of propellants (and hence, a smaller vehicle), or, alternately, that the mission can be accomplished with a larger payload than is possible with the same mass of conventional propellants. In short, hydrogen yields a bigger bang for the buck.

Hypergolic:

Hypergolic propellants are fuels and oxidizers which ignite on contact with each other and need no ignition source. This easy start and restart capability makes them attractive for both manned and unmanned spacecraft maneuvering systems. Another plus is their storability – they do not have the extreme temperature requirements of cryogenics.

The fuel is monomethylhydrazine (MMH), and the oxidizer is nitrogen tetroxide (N2O4).

Hydrazine is a clear, nitrogen/hydrogen compound with a "fishy" smell. It's similar to ammonia.

N2O4 is a brownish fluid which might be described as a super nitric acid. It has the sharp, acrid smell of many acids. Both fluids are highly toxic, and are handled under the most stringent safety conditions.

Hypergolic propellants are used in the liquid propellant stages of the Titan class of launch vehicles, including the Titan III-E/Centaur series which was used by NASA to launch the Helios sun probes and the Viking and Voyager planetary explorers.

The Space Shuttle orbiter uses hypergols in its Orbital Maneuvering Subsystem (OMS) for orbital insertion, major orbital maneuvers and deorbit. The Reaction Control System (RCS) uses hypergols for attitude control.

The efficiency of the MMH/N2O4 combination in the Space Shuttle orbiter ranges from 260 to 280 seconds in the RCS to 313 seconds in the OMS. The higher efficiency of the OMS system is attributed to higher expansion ratios in the nozzles and higher pressures in the combustion chambers.

Solid:

The solid propellant motor is the oldest and simplest of all forms of rocketry, dating back to the ancient Chinese. It is simply a casing, usually steel, filled with a mixture of solid-form chemicals (fuel and oxidizer) which burn at a rapid rate, expelling hot gases from a nozzle to achieve thrust.

Solids require no turbopumps or complex propellant feed systems. Ignition is by a simple squib device at the top of the motor which directs a high-temperature flame along the surface of the propellant grain, igniting it instantaneously.

The propellant, a rubbery substance with the consistency of a hard rubber eraser, has a star-shaped (other shapes are possible) hollow channel extending through the center. When ignited the propellant burns from the center out toward the sides of the casing. The shaped center channel exposes more or less burning area at any given point in time, thus providing a means to vary the thrust of the expelled gases.

Solid propellants are easily storable and stable. Unlike liquid propellant engines, though, a solid propellant motor cannot be shut down. Once ignited, it will burn until all propellant is exhausted.

Solids are used in a variety of ways for space operations. Small solids often power the final stage of a launch vehicle, or are attached to payload elements to boost satellites and spacecraft to higher orbits.

Medium solids such as the Payload Assist Module (PAM) and the Inertial Upper Stage (IUS) provide the added boost to place satellites into geosynchronous orbit or on planetary trajectories.

The PAM is used for payload boost on the Delta and Space Shuttle. The IUS is carried by the Space Shuttle and the Titan III class of launch vehicles.

Only one of the nation's stable of launch vehicles uses solids exclusively. This is NASA's Scout, a four-stage rocket used to orbit small satellites.

Titan, Delta and Space Shuttle vehicles depend on solid rockets to provide added thrust at liftoff.

The Space Shuttle uses the largest solid rocket motors ever built and flown. Each, which is reusable, contains 498,951 kilograms (1.1 million pounds) of propellant.

This propellant consists of an aluminum powder (16 percent) as a fuel; ammonium perchlorate (69.93 percent) as an oxidizer; iron oxidizer powder (.07 percent) as a catalyst; polybutadiene acrylic acid acrylonitrile (12.04 percent) as a rubber-based binder; and an epoxy curing agent (1.96 percent). The binder and epoxy are also burned as a fuel, adding thrust.

The specific impulse of the Space Shuttle solid rocket booster propellant is 242 seconds at sea level and 262 seconds at altitude.

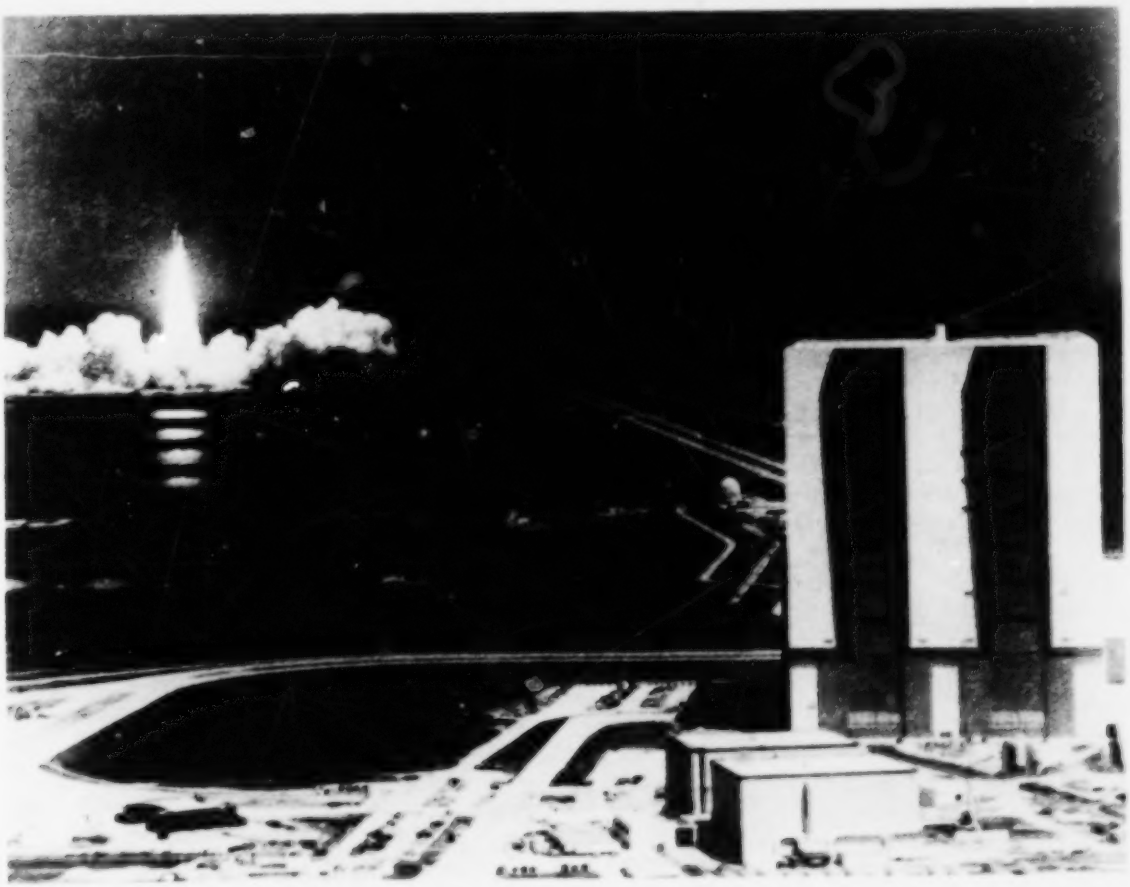
Facilities and Operations

NASA conducts launch operations for its current stable of launch vehicle at several sites across the country. The Scout rocket is launched by the Langley Research Center from facilities at Vandenberg Air Force Base in California, and from the Wallops Flight Facility on the east coast of Virginia. Visiting teams from Italy occasionally launch Scouts from San Marco, a man-made platform in the ocean off the east coast of Africa.

The Kennedy Space Center, the nation's primary launch organization, prepares and launches unmanned Deltas and Atlas-Centaur rockets from facilities at Complexes 17 and 36 on Cape Canaveral Air Force Station, Florida. Manned Space Shuttle launches are conducted from Launch Complex 39, located at the northern tip of Cape Canaveral.

The Complex 39 facilities at Kennedy Space Center originally were built to support the Apollo Lunar Landing Program. From 1967 to 1975, 12 Saturn V/Apollo vehicles, one Saturn V/Skylab workshop, three Saturn IB/Apollo vehicles for the Skylab crews, and one Saturn IB/Apollo for the joint U.S.-Soviet Apollo-Soyuz mission were launched from Complex 39. These facilities then were modified to process and launch the Space Shuttle. Reworking existing facilities was far less expensive than building all new structures. Two major new additions were added – a special runway to land returning orbiters and an orbiter checkout hangar called the Orbiter Processing Facility. During the 1980s, a number of new facilities were added for solid rocket booster processing and Shuttle logistics.

These facilities, and how they support Space Shuttle operations, are explained on the following pages.



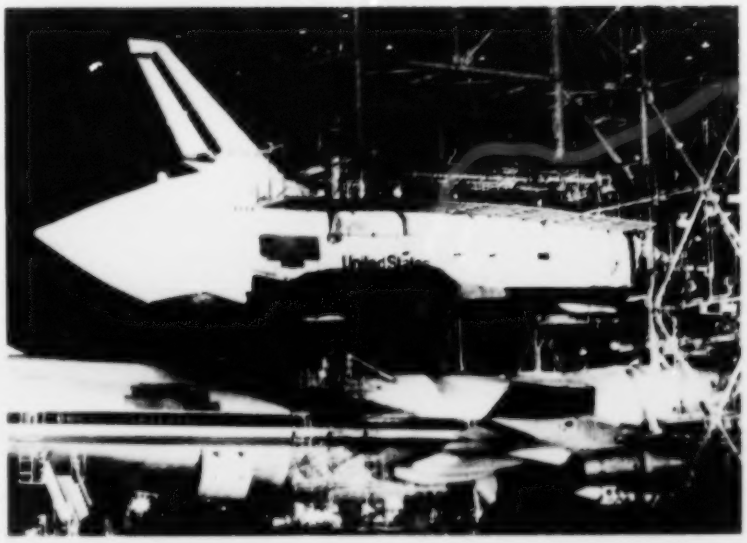
Launch Complex 39, Kennedy Space Center.

Shuttle Landing Facility

When an operational Space Shuttle orbiter returns to Earth from its mission in space and lands at the Kennedy Space Center, it touches down on one of the world's longest runways. This facility is located two miles northwest of the Vehicle Assembly Building, on a northwest/southeast alignment.

The Shuttle Landing Facility runway is about twice the length and width of those used at commercial airports. It is 4,572 meters (15,000 feet) long, 91.4 meters (300 feet) wide, and 40.5 centimeters (16 inches) thick at the center. Safety overruns of 305 meters (1,000 feet) are provided at each end. The runway is not perfectly flat, but has a slope of 61 centimeters (24 inches) from the centerline to the edge. Small grooves, each 0.63 centimeter (0.25 inch) wide and deep, have been cut into the concrete every 2.85 centimeters (1.25 inches) across the runway. There are a total of 13,600 kilometers (8,450 miles) of these grooves. Together with the slope of the concrete they provide rapid drain-off of rain, as well as a more skid resistant surface.

A 168-meter (550-foot) by 149-meter (490-foot) aircraft apron, or ramp, is attached to the runway near the southeastern end. The Mate/Demate Device, which lifts the orbiter for attachment to or removal from its 747 carrier aircraft during ferry operations, is located on the northeast corner of the ramp. It also provides movable platforms for access to certain orbiter components.

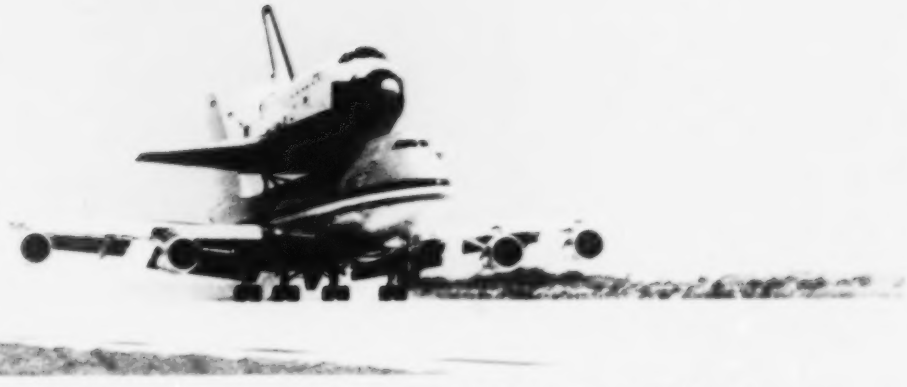


An orbiter in the Mate/Demate Device has just been lifted from the 747 carrier aircraft used in ferry operations.

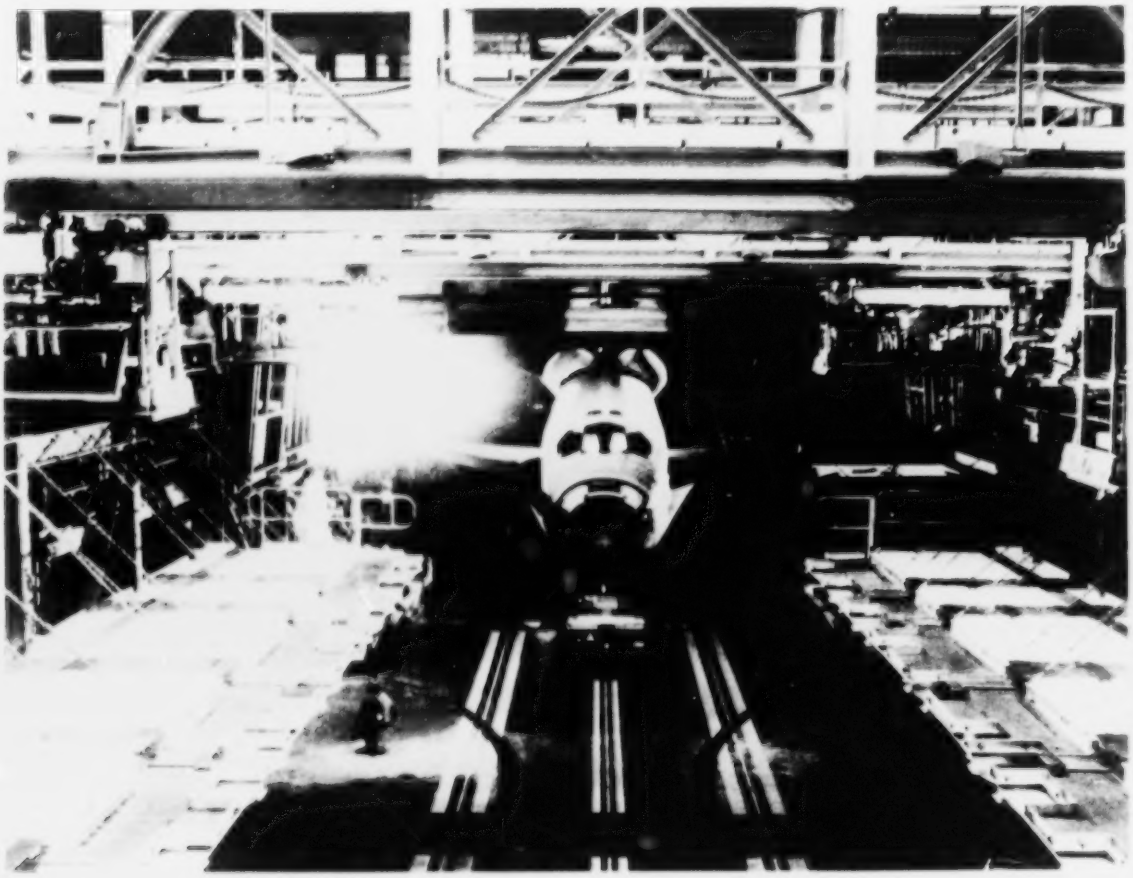
A Tactical Air Navigation (TACAN) station is located at midfield off the east side of the runway. This is a homing transmitter that broadcasts a signal receivable by the orbiter. The TACAN has a range of 483 kilometers (300 miles) and is received when the spacecraft emerges from the re-entry blackout period. The final approach is guided by a precision Microwave Scanning Beam Landing System, which is accurate to within 99.33% in bringing the orbiter to the designated point on the runway.

Unlike conventional aircraft, the orbiter lacks propulsion during the landing phase. Its high-speed glide must bring it in for a landing perfectly the first time – there is no circle-and-try-again capability. The landing speed of the orbiter is 346 kilometers (215 miles) per hour.

Landings may be made on the runway from the northwest to



An orbiter/747 combination touching down on the extra-long runway at the Shuttle Landing Facility.



Orbiter Columbia is towed into Orbiter Processing Facility to begin processing for a mission.

southeast (Runway 15) or from the southeast to northwest (Runway 33). The landing system ground equipment is duplicated to permit an approach from either direction. Shuttle landings also are made at Edwards AFB, California.

Orbiter Processing Facility

Space Shuttle orbiters are processed between missions in a structure analogous to a sophisticated aircraft hangar — the Orbiter Processing Facility. Capable of handling two orbiters in parallel, this facility is located to the west of the Vehicle Assembly Building.

The Orbiter Processing Facility consists of two identical high bays connected by a low bay. The high bays are each 60 meters (197 feet) long, 46 meters (150 feet) wide, and 29 meters (95 feet) high. Each is equipped with two 27-metric ton (30-ton) bridge cranes, and contains platforms which effectively surround the orbiter to provide personnel access. The high bay areas have an emergency exhaust system in case of a fuel spill, and fire protection systems are installed throughout the facility. The low bay separating the two high bays is 21 meters (233 feet) long, 30 meters (97 feet) wide, and eight meters (25 feet) high. The low bay houses electronic, mechanical, and electrical support systems, as well as shops and office space.

Spacecraft processed through checkout in a horizontal attitude, such as the Hubble Space Telescope, are loaded into the orbiter in the Orbiter Processing Facility. Spacecraft that are checked out and installed in a vertical attitude are mated with the orbiter at the launch pad.

The processing of the solid rocket motor segments, as they arrive by barge at the Kennedy Space Center, is also accomplished in the Orbiter Processing Facility. The solid rocket motor segments are processed in the Solid Rocket Booster Assembly and Refurbishment Facility, which is located to the north of the Orbiter Processing Facility.

Orbiter Modification and Refurbishment Facility

Located just northwest of the Vehicle Assembly Building, the 4,645 square meter (50,000 square foot) facility is used for performing modification, rehabilitation, and overhaul of Space Shuttle orbiters outside of the facilities used in the normal operational flow. The building consists of a high bay 29 meters (95 feet) high and a two-story low bay area. It contains special work platforms, storage and parts areas, offices, and special tools and equipment needed to perform orbiter modifications that do not require an orbiter to be moved

facturing facilities in California.

Logistics Facility

This modern, 30,159 square meter (324,640 square foot) facility is located south of the Vehicle Assembly Building and houses some 190,000 shuttle hardware parts and over 500 NASA and contractor personnel. A unique feature of the building is its state-of-the-art storage and retrieval system which includes automated handling equipment to find and retrieve specific parts.

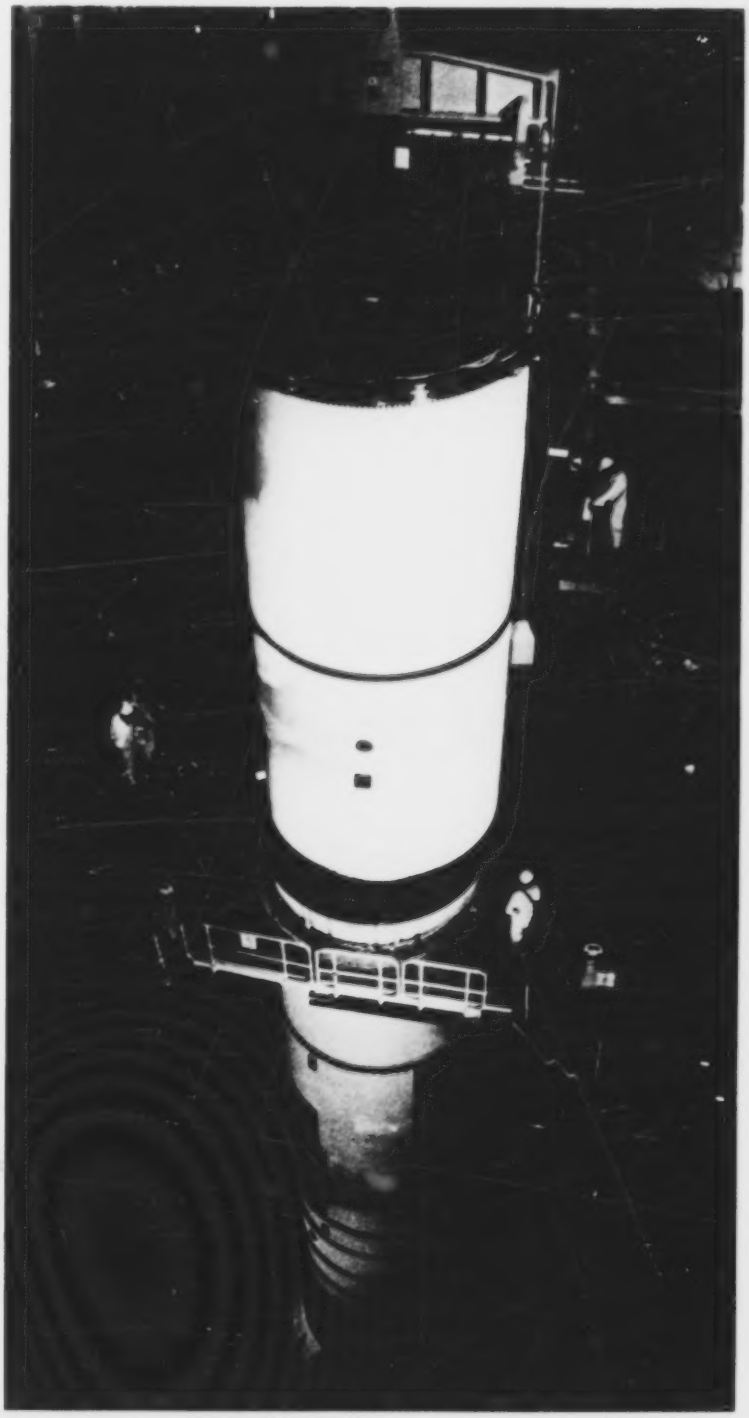
Solid Rocket Booster Processing

Following a Space Shuttle launch, the expended solid rocket boosters parachute into the ocean. They are retrieved by recovery ships and towed back to facilities on Cape Canaveral Air Force Station for disassembly and cleaning. The empty propellant-carrying segments are transferred to booster processing facilities at Complex 39, where they are prepared for shipment by rail to the manufacturer for propellant reloading. The remaining solid rocket booster components are taken to an assembly and refurbishment area adjacent to Complex 39 for reconditioning, assembly and testing.

The solid rocket booster launch processing flow is as follows:

Rotation Processing Building: Located just north of the Vehicle Assembly Building, this facility receives new and reloaded solid rocket booster segments – aft, aft center, forward and forward center – shipped by rail from the manufacturer. Here, inspection, rotation and aft skirt/aft segment buildup are performed.

Assembly and Refurbishment Facility: This facility, located several miles south of the Vehicle Assembly Building covers 45 acres and consists of four main buildings – Manufacturing, Engineering and Administration, Service, and Hot Fire. Inert booster components such as the aft and forward skirts, frustums, nose caps, recovery systems, electronics and instrumentation, and elements of the thrust vector control system are received, refurbished, assembled and tested. Completed aft skirt



Assembly of the Space Shuttle flight components takes place in High Bays 1 or 3 of the Vehicle Assembly Building. One of the Shuttle's two solid rocket boosters is being stacked on the Mobile Launcher Platform. The external tank will next be mated to the boosters.

assemblies are transferred to the Rotation Processing Building for integration with the aft segments. The remaining components are integrated with the booster stack during mating operations inside the Vehicle Assembly Building.

SURGE Buildings (2): Each of these facilities are used to store two solid rocket booster flight sets (eight segments) after transfer from the adjacent Rotation Processing Building. They remain here until moved to the Vehicle Assembly Building for integration with other flight-ready booster components from the Assembly and Refurbishment Facility.

Vehicle Assembly Building: All booster elements are integrated here into complete flight sets and mated with the Space Shuttle orbiter and external tank.

External Tank

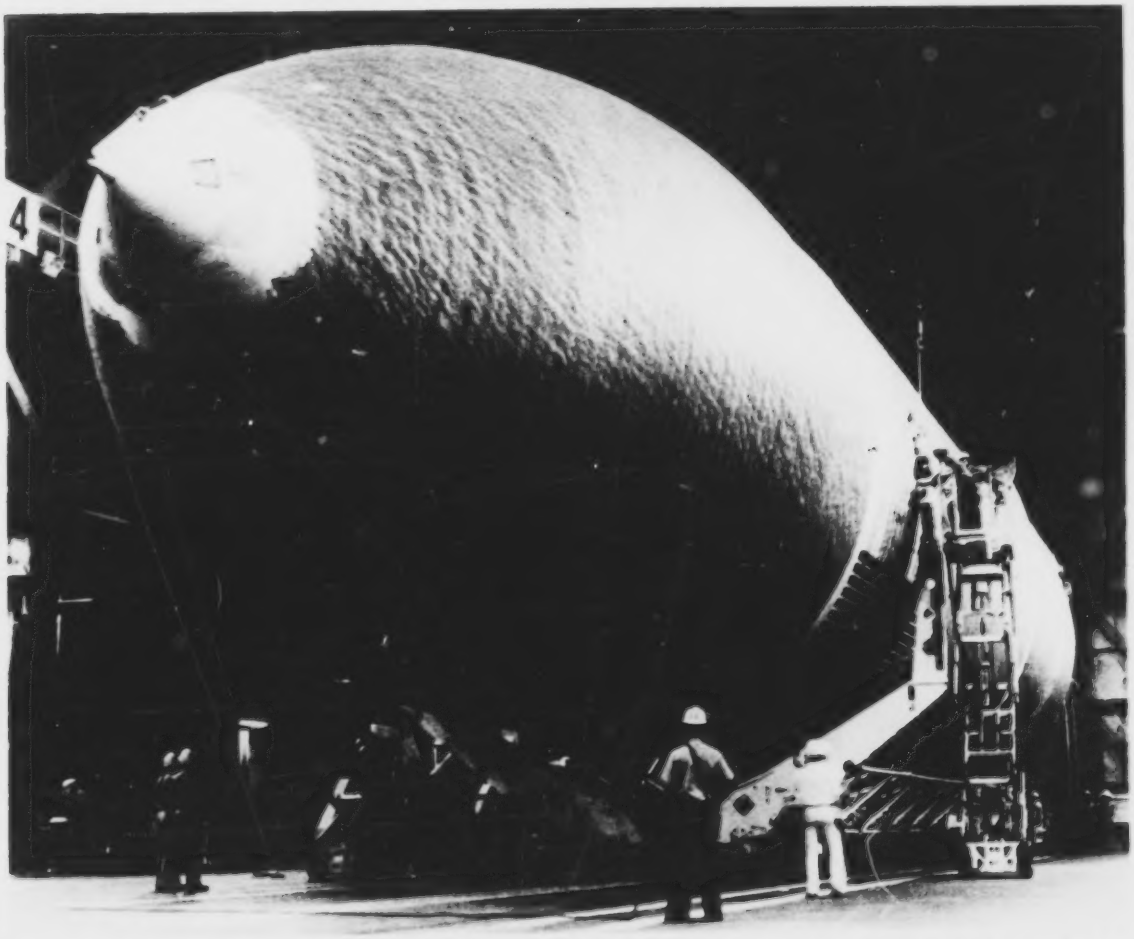
The external tank is transported by barge from its manufacturing site at Michoud, Louisiana, to Kennedy Space Center. It is offloaded at the Complex 39 turn basin and transferred into the Vehicle Assembly Building where it is processed and stored in the high bay area until mating with the other Space Shuttle flight elements.

The external tank is the largest element of the Space Shuttle system. It contains two inner tanks which hold the liquid oxygen and liquid hydrogen propellants that are fed into the orbiter's main engines during the ascent phase of launch. It is the only Space Shuttle component that is not recovered and reused.

Vehicle Assembly Building

After preparation in the Orbiter Processing Facility, the orbiter is towed to the Vehicle Assembly Building. This is the heart of Launch Complex 39 and has been modified for use in assembling the Space Shuttle vehicle.

One of the largest buildings in the world, the Vehicle Assembly Building covers a ground area of 32,376 square meters (eight acres) and has a volume of 3,624,000 cubic meters (129,428,000 cubic feet). It is 160 meters (525 feet) tall, 218 meters (716 feet) long and



The external tank rests on its trailer in the transfer aisle of the Vehicle Assembly Building after arriving at the Kennedy Space Center by barge.

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158 meters (518 feet) wide. The building is divided into a high bay area 160 meters (525 feet) tall, and a low bay area which is 64 meters (210 feet) tall.

The structure is designed to withstand winds of up to 200 kilometers (125 miles) per hour. Its foundation rests on more than 4,200 steel pilings 40 centimeters (16 inches) in diameter, driven down to bedrock at a depth of 49 meters (160 feet).

The Vehicle Assembly Building has more than 70 lifting devices, including two 227-metric ton (250-ton) bridge cranes.

The Low Bay area contains Space Shuttle main engine maintenance and overhaul shops, and serves as a holding area for solid rocket booster forward assemblies and aft skirts.

High Bays 1 and 3 are used for integration and stacking of the complete Space Shuttle vehicle. High Bay 2 is used for external tank checkout and storage and as a contingency storage area for orbiters. High Bay 4 also is used for external tank checkout and storage, as well as for payload canister operations and solid rocket booster contingency handling.

During Space Shuttle buildup operations inside the Vehicle Assembly Building, integrated solid rocket booster segments are transferred from nearby assembly and checkout facilities, hoisted onto a Mobile Launcher Platform in High Bays 1 or 3 and mated together to form two complete solid rocket boosters. The external tank, after arrival by barge, and subsequent checkout, inspection and storage in High Bays 2 or 4, is transferred to High Bays 1 or 3 to be attached to the solid rocket boosters already in place. The orbiter, the final element to be added, is towed from the Orbiter Processing Facility to the Vehicle Assembly Building transfer aisle, raised to a vertical position by overhead cranes, lowered onto the Mobile Launcher Platform and mated to the rest of the stack.

When assembly and checkout operations are complete, the huge outer doors of a high bay open to permit the Crawler-Transporter to enter and move under the Mobile Launcher Platform holding the as-

After being towed into the Vehicle Assembly Building the orbiter is raised to the vertical position and lifted into the high bay by bridge crane for mating with the external tank.

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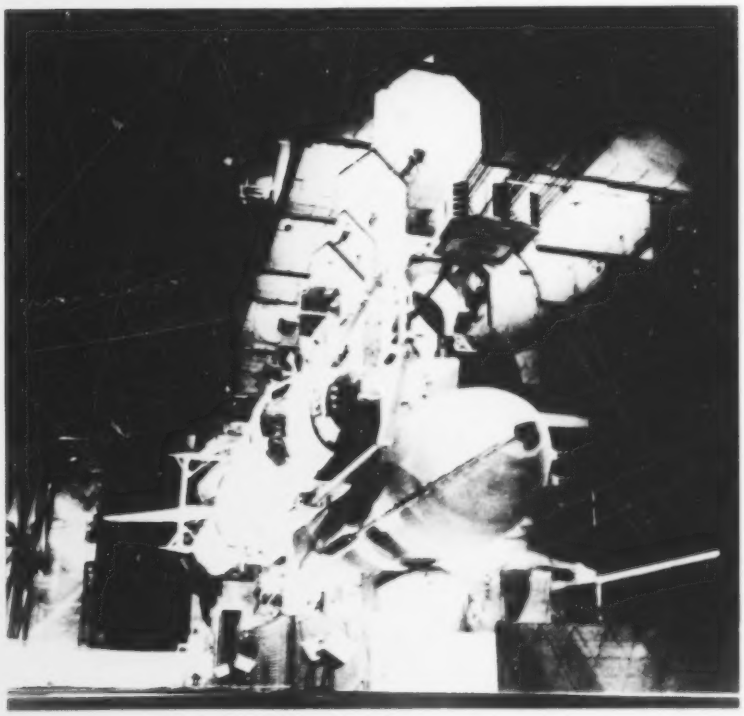


The orbiter is lowered into position in the high bay to be attached to the external tank.

In firing room 1 at the Launch Control Center are consoles for the Launch Processing System, which is used for the checkout and launch of the Space Shuttle. Identical firing rooms enable a second Space Shuttle to be processed in parallel.

sembled Shuttle vehicle. These high bay doors are 139 meters (456 feet) high from ground to top. Seven 23 meter (76 foot) wide sliding panels rise vertically into a protected enclosure near the top of the building. Four panels at the bottom move apart horizontally, to create an opening that is 46 meters (152 feet) wide and 35 meters (114 feet) high. The Mobile Launcher Platform is so huge it forms a fairly snug "fit" within these dimensions.

Launch Control Center

If the Vehicle Assembly Building is the heart of Launch Complex 39, the Launch Control Center is its brain. This is a four-story structure on the east side of the Vehicle Assembly Building and connected with it by an elevated, enclosed bridge.

The Launch Control Center contains four firing rooms that are used to conduct NASA and classified military launches. Each is equipped with the Launch Processing System which monitors and controls most Space Shuttle assembly, checkout, and launch operations.

The Space Shuttle final countdown requires approximately five hours, compared to 28 hours for a Saturn-Apollo countdown. Launches utilizing the Launch Processing System require approximately 90 personnel in the firing room as compared with 450 needed for previous manned missions.

The Launch Processing System consists of two major parts, the Central Data Subsystem and the Checkout, Control, and Monitor Subsystem.

The Central Data Subsystem operates four computers that store test procedures, vehicle processing data, a master program library, historical data, and pre-test post-test analyses. The Central Data Subsystem is located on the second floor of the Launch Control Center.

The operators of the Checkout, Control, and Monitor Subsystem utilize consoles, mini-computers, a large mass storage unit, and other related equipment located in the firing rooms to actually process and launch the vehicle. Shuttle checkout, countdown, and launch operations are conducted with the support of the information stored in the Central Data Subsystem.

The Mobile Launcher Platform and assembled Space Shuttle on the Crawlerway

Transportable Equipment

The **Mobile Launcher Platform** is a steel structure 7.6 meters (25 feet) high, 49 meters (160 feet) long, and 41 meters (135 feet) wide. It serves as a transportable launch base for the Space Shuttle. The platform is constructed of steel and has 16 reinforced concrete decks. At their parking sites north of the Vehicle Assembly Building, in the high bays, and at the launch pads, the two Mobile Launcher Platforms rest on six 6.7-meter (22-foot) tall pedestals. There are three openings through the main body of a platform. Two are for the exhaust of the solid rocket boosters, and the third — the one in the center — is for the Shuttle main engines exhaust.

Two large devices called Tail Service Masts sit on each side of the Space Shuttle at the main engines exhaust hole. They provide several umbilical connections to the orbiter, including a liquid oxygen line running through one and a liquid hydrogen line through the other. These cryogenic propellants are fed into the external tank from the fuel tanks via these connections. At launch the umbilicals are pulled away from the orbiter and retract into the masts, where protective hoods rotate closed to shield them from the exhaust flames. Each Tail Service Mast assembly is 45 meters (15 feet) long, 2.7 meters (nine feet) wide, and rises 9.4 meters (31 feet) above the platform deck.

The **Hydrogen Burnoff System** consists of two 15-meter (5-foot) long booms, one suspended from each Tail Service Mast. Each boom contains four flare-like devices which are designed to burn off gas from a pre-ignition flow of liquid hydrogen through the main engines. This is to keep a cloud of explosive hydrogen from forming which could explode upon ignition of the main engines.

The Payload Canister in the vertical position on its transporter.

The Space Shuttle is supported and held on the Mobile Launcher Platform by eight attach posts, four on the aft skirt of each of the two solid rocket boosters. These fit on counterpart posts located in the platform's two solid rocket booster support wells. The vehicle is freed by triggering explosive nuts which release the giant studs linking the solid rocket booster attach posts with the platform support posts.

There are two inner levels in each Mobile Launcher Platform, with various rooms that house electrical, test, and propellant loading equipment. Unloaded, a Mobile Launcher Platform weighs 3.7 million kilograms (8.23 million pounds).

The two **Crawler-Transporter** tracked vehicles were previously used to move Saturn rockets from the Vehicle Assembly Building to the launch pad. The transporters are 6.1 meters (20 feet) tall, 40 meters (131 feet) long and 35 meters (114 feet) wide. The maximum speed unloaded is 3.2 kilometers (two miles) per hour, while maximum speed with the load of the Space Shuttle is 1.6 kilometers (one mile) per hour. A crawler has eight tracks, each of which has 57 shoes, or cleats. Each shoe weighs approximately one ton. Unloaded, the transporter weighs 2,857,680 kilograms (6.3 million pounds).

The transporters have a leveling system that will keep the top of the Space Shuttle vertical while negotiating the five-percent grade leading up to the top of the launch pad.

The transporter is powered by two 2,750-horsepower diesel engines. The engines drive four 1,000-kilowatt generators which provide electrical power to the 16 traction motors.

The **Payload Canister** provides restraint and protection to the various Shuttle payloads while in transit from payload processing or assembly facilities to either the launch pad (vertically handled payloads) or Orbiter Processing Facility (horizontally handled payloads). The canister is 21 meters (69 feet) long, 6.4 meters (21 feet) wide and 6.4 meters (21 feet) high.

The canister is made to physically resemble the cargo bay of the orbiter. It can accommodate payloads up to 18.3 meters (60 feet) long, 4.5 meters (15 feet) in diameter, and up to 29,481 kilograms (65,000 pounds) in weight. It provides environmental control and protection to payloads while in transit, and can supply certain needed support services such as gas purges and monitoring of critical measurements.

The **Payload Canister Transporter** is a 48-wheel self-propelled truck designed to transport the canister and its associated hardware. The transporter rides on rubber tires and is designed to operate on normal hard road surfaces. It is 19.8 meters (65 feet) long and 7 meters (23 feet) wide. Its elevating flatbed has a height of 1.8 meters (6 feet) but can be lowered to 1.6 meters (5 feet 3 inches) or raised to 2.1 meters (7 feet). Its wheels are independently steerable and permit the transporter to move forward, backward, or sideways; to "crab" diagonally; or to turn on its own axis like a carousel.

The transporter is driven by a hydraulic system powered by a liquid-cooled diesel engine. However, when within a spacecraft facility the transporter runs on an electric motor using ground power.

The bare transporter weighs 63,500 kilograms (140,000 pounds). With a full load of diesel fuel, the environmental control system, communications systems, and other equipment and instrumentation mounted on it, the transporter has a gross weight of 77,300 kilograms (170,500 pounds).

The transporter is steerable from diagonally opposed operator cabs on each end. Its top speed unloaded is 16 km/h (10 mph), but fully loaded it is 8 km/h (5 mph). Because payload handling will require precise movements, the transporter has a "creep" mode that permits it to move as slowly as 0.023 km/h (0.014 mph). The transporter can carry the payload canister in either the horizontal or vertical position.

The Crawler-Transporter can lift the Space Shuttle on its Mobile Launcher Platform and move it from the Vehicle Assembly Building to the launch pad.

Crawlerway

The Crawler-Transporters move on a roadway 40 meters (130 feet) wide, almost as broad as an eight-lane turnpike. The crawlerway consists of two 12-meter (40-foot) wide lanes, separated by a 15-meter (50-foot) wide median strip, that run from the Vehicle Assembly Building to the launch pads. The top surface on which the transporters operate is river gravel. This gravel layer is 20 centimeters (eight inches) thick on curves and half that on the straightaway sections. The distance from the Vehicle Assembly Building to Pad 39A is about 5.6 kilometers (3.5 miles), and to Pad 39B, 6.8 kilometers (4.25 miles).

Launch Pads 39A And 39B

The Launch Complex 39 pads are roughly octagonal in shape. Each covers about 0.64 square kilometer (0.25 square mile) of land, contained within a high chain link fence. Space Shuttles are launched from the top of the concrete hardstand in the center of the pad. The Pad A stand is 14.63 meters (48 feet) above sea level at its top, and Pad B is 16.76 meters (55 feet). The top of each pad measures 119 meters (390 feet) by 99 meters (325 feet). The two major items of equipment on each pad are the Fixed Service Structure and the Rotating Service Structure.

The *Fixed Service Structure* is located on the west side of the hardstand. A hammerhead crane on top provides hoisting services as required in pad operations. There are 12 work levels at six-meter (20-foot) intervals. The height of the structure to the top of the tower is 75 meters (247 feet), to the top of the hammerhead crane 81 meters (265 feet), and to the top of the lightning mast 106 meters (347 feet).

Swingarms on the Fixed Service Structure provide access to the orbiter for crew and equipment. The Orbiter Access Arm swings out to the crew compartment to provide personnel access. The outer end of this arm supports a small room, holding up to 6 persons, commonly called the "White Room." It mates with the crew hatch. This arm remains in the extended position until seven minutes prior to launch, to provide an emergency exit for the crew should one be needed. It is 20 meters (65 feet) long, 1.5 meters (5 feet) wide, and 2.4 meters (8 feet) high. The Orbiter Access Arm is attached to the Service Structure at the 44.8-meter (147-foot) level. It rotates to its retracted position in approximately 30 seconds.

The External Tank Gaseous Oxygen Vent Arm lowers a hood, called the beanie cap, over the top of the Shuttle's external fuel tank. Heated gaseous nitrogen is pumped into the hood to warm the liquid oxygen vent system at the top of the external tank. This prevents vapors at the vent opening from condensing into ice that could dislodge and damage the orbiter during launch. The vent system arm is 24.4 meters (80 feet) long, 1.5 meters (5 feet) wide, and 2.4 meters (8 feet) high. The diameter of the vent hood is 4 meters (13 feet). The arm is attached to the Fixed Service Structure between the 63.1-meter (207-foot) and 69.2-meter (227-foot) levels. The arm and its hood can be retracted in about one minute and 30 seconds. They are in the fully retracted position at approximately 45 seconds prior to launch.

The External Hydrogen Vent Line Access Arm provides a means of mating the external tank umbilicals to the pad facilities, and provides work access to the tank area.

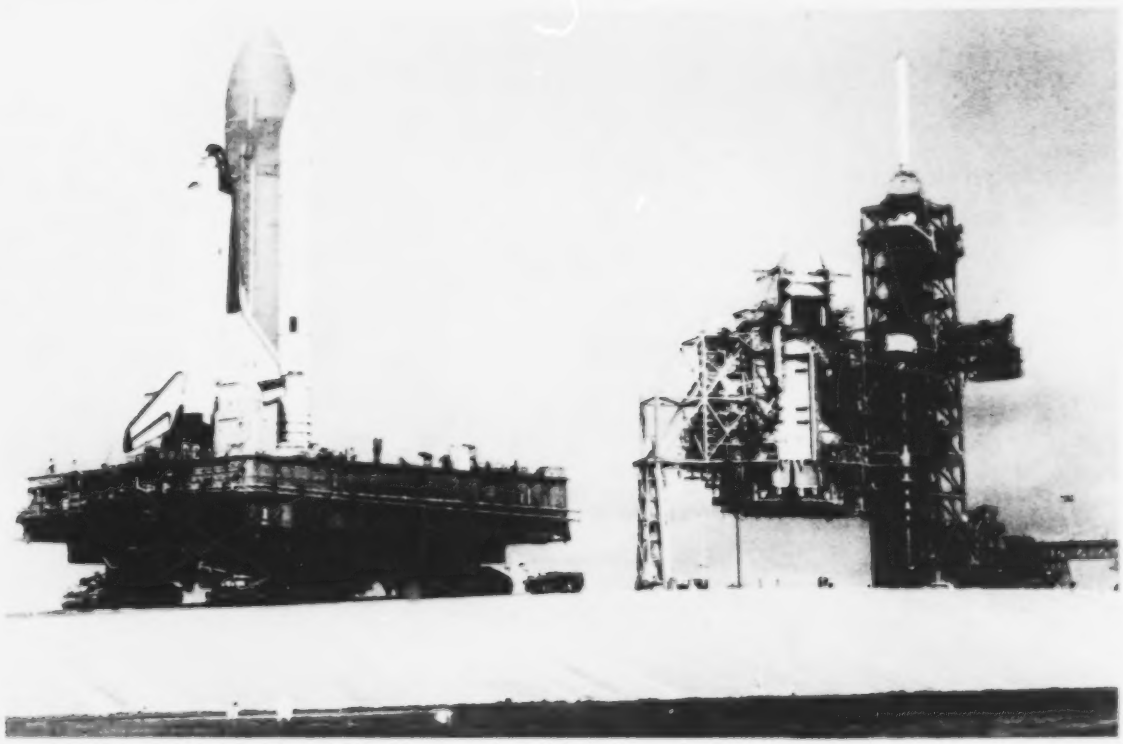
This arm retracts several hours before launch, leaving the umbilicals attached. At the moment the solid rocket boosters ignite, these umbilicals eject from the Shuttle and fall back against the tower, where they are protected from engine flame by a curtain of sprayed water. This arm is 15 meters (48 feet) long, and attached at the 51-meter (167-foot) level.

The *Rotating Service Structure* provides access to the orbiter for installation and servicing of payloads at the pad. It pivots through one-third of a circle, from a retracted position well away from the Shuttle to the point where its payload changeout room doors meet and match the orbiter cargo bay doors. It rotates around a vertical hinge attached to one corner of the Fixed Service Structure. Most of its body is some 18 meters (59 feet) above the pad, supported by the hinge and a structural framework on the opposite end. This framework rests on two eight-wheel motor-driven trucks, which ride on rails installed with the pad surface. The rotating body is 31 meters (102 feet) long, 15 meters (50 feet) wide, and 40 meters (130 feet) high.

The primary purpose of the Rotating Service Structure is to receive Space Shuttle payloads while in the retracted position, rotate, and install them in the orbiter cargo bay. With the exception of the Spacelab and other large horizontal payloads, which are loaded while the orbiter is in the Orbiter Processing Facility, all spacecraft are loaded into the Shuttle at the pad. The payload changeout room provides an environmentally clean or "white room" condition in which to receive payloads from their protective transportation canisters, and maintains this cleanliness by never exposing the spacecraft to the open air during the transfer operations.

In operation, a canister is hoisted to the proper elevation in the retracted Rotating Service Structure and locked into position. The environmental seals in the Rotating Service Structure are inflated against the sides of the canister. The space between the closed doors of the Rotating Service Structure and the canister are purged with clean, temperature and humidity-controlled air, after which the doors may be opened. The payload is then transferred from the canister into the Rotating Service Structure, the canister and Rotating Service Structure doors are closed, the environmental seal is deflated, and the canister is lowered to its transporter to be taken off the pad. The Rotating Service Structure rolls into position to enclose the orbiter's payload bay, re-establishing the environmental seals and clean air purge. The Rotating Service Structure and payload bay doors are then opened so that the payload may be installed.

A Weather Protection System at Pads A and B shields the orbiter from windblown debris, heavy rains and hail that could damage the craft's fragile heat protection tiles. A considerable portion of the orbiter is shielded by the Rotating Service Structure and its attached

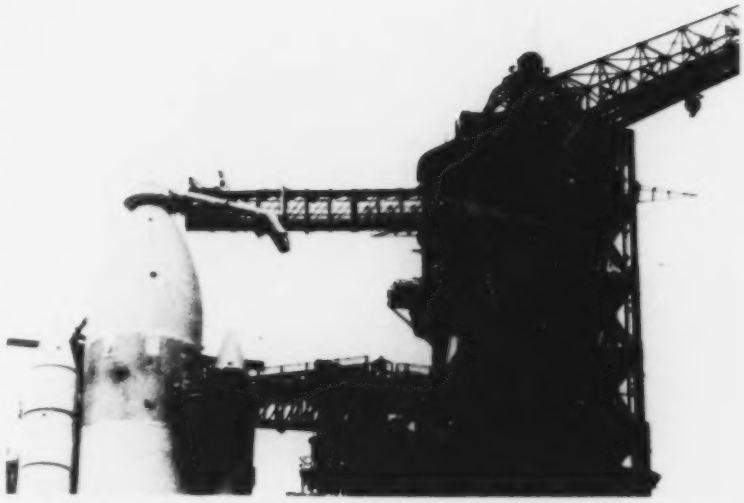


Pad 39A, with its Fixed and Rotating Service Structures, prepares to accept the Space Shuttle on its Mobile Launcher Platform. The Shuttle is being carried up the pad ramp by the Crawler-Transporter.

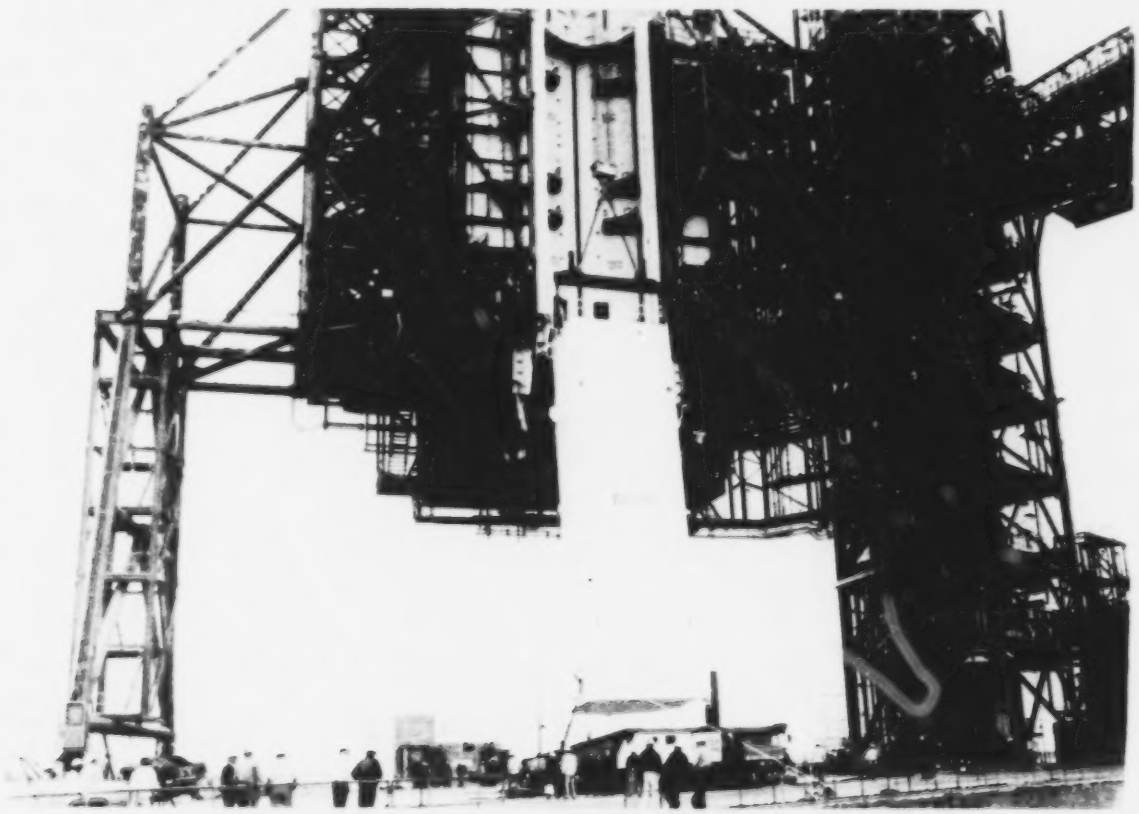
Payload Changeout Room which closes in around the vehicle while on the pad. The Weather Protection System fills in the gaps.

Protection for the lower portion of the orbiter is provided by metal doors that slide together between the orbiter's belly and the external tank. The doors, measuring up to 16 meters (53 feet) long, 11.6 meters (38 feet) tall and weighing up to 21 metric tons (46,000 pounds), are connected to the Rotating Service Structure and the Fixed Service Structure. The doors move together from opposite sides on wheeled flanges that ride on steel beams.

The top of the orbiter is protected by an inflatable seal that extends from the Payload Changeout Room, forming a semi-circle covering 90 degrees of arc between the vehicle and the external tank. A series of 20 or more bi-fold metal doors, about 24.4 x 1.2



Attached to the top of the Fixed Service Structure is the gaseous oxygen vent hood on its swingarm. Underneath, the external tank hydrogen vent line and access arm allows mating of umbilicals and access to the intertank interior.



The Payload Canister is lifted from its transporter into the cradle of the Rotating Service Structure.

meters (80 x 4 feet) in size, fold out from the Payload Changeout Room on the Rotating Service Structure to cover the side areas between the external tank and the orbiter.

The *Flame Deflector System* protects the vehicle and pad structures from the intense heat of launch. It is located in the ground level flame trench that bisects the hardstand. A flame deflector functions by presenting an inverted V-shape to the flames pouring into the trench through openings in the Mobile Launcher Platform. Both sides of the upside-down V curve out near the bottom until they are almost horizontal. Flames follow these curves and are deflected horizontally down the flame trench, rather than bouncing back up to envelop the vehicle.

The flame trench divides the hardstand lengthwise from ground level to the pad surface. It is 149 meters (490 feet) long, 18 meters (58 feet) wide, and 12 meters (40 feet) high. At launch, flames shoot out both ends of the trench into the air. The deflector for the Space Shuttle is actually a two-in-one device, where one side of the inverted V receives the flames from the orbiter's main engines, and the opposite side the flames from the two solid rocket boosters. It is fixed near the center of the trench, and extends completely across it.

The orbiter and booster deflectors are built of steel and covered with an ablative material about 13 centimeters (five inches) thick that flakes off to shed heat. They weigh over 453,592 kilograms (one million pounds) each.

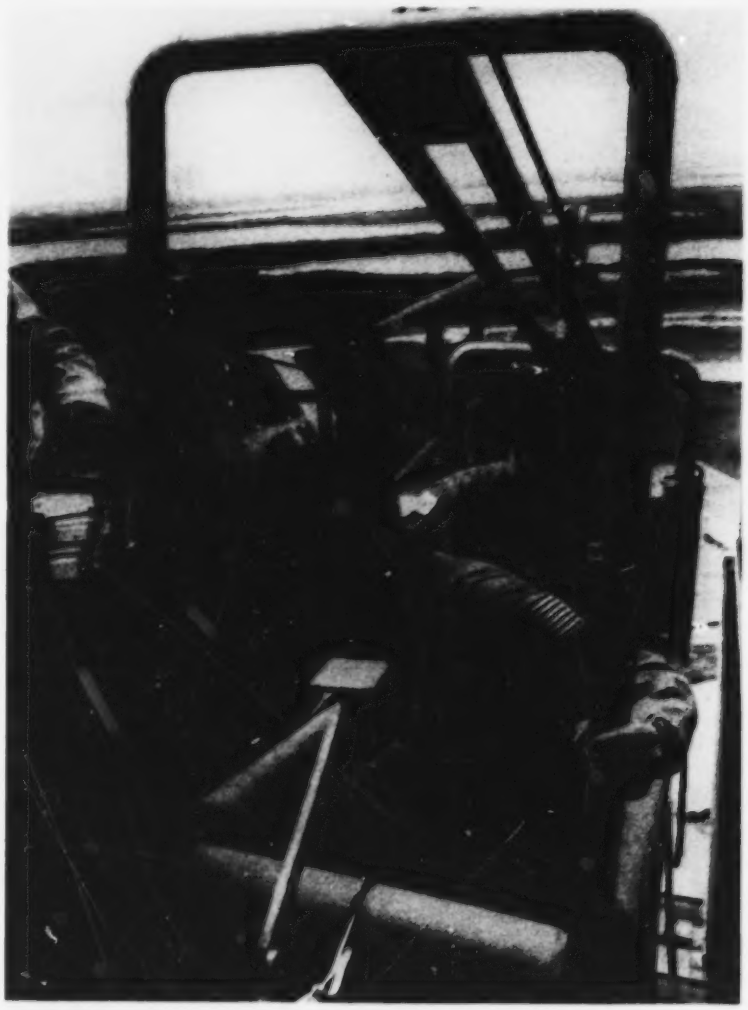
In addition to the fixed deflectors, there are two movable ones located at the top of the trench, for additional protection from the solid rocket booster flames.

The *Slidewire System* provides an escape route for the astronauts and closeout crew until the final 30 seconds of countdown. Five slidewires extend from the Fixed Service Structure at the Orbiter Access Arm level down to the ground. A flat-bottom basket made of steel wire and heat resistant fiber is suspended from each of five wires and positioned for entry in event of emergency. Each basket can hold two persons. The basket slides down a 366-meter (1,200 foot) wire to a bunker located west of the Fixed Service Structure. The descent takes approximately 35 seconds and is controlled by a friction brake between the basket and the wire.

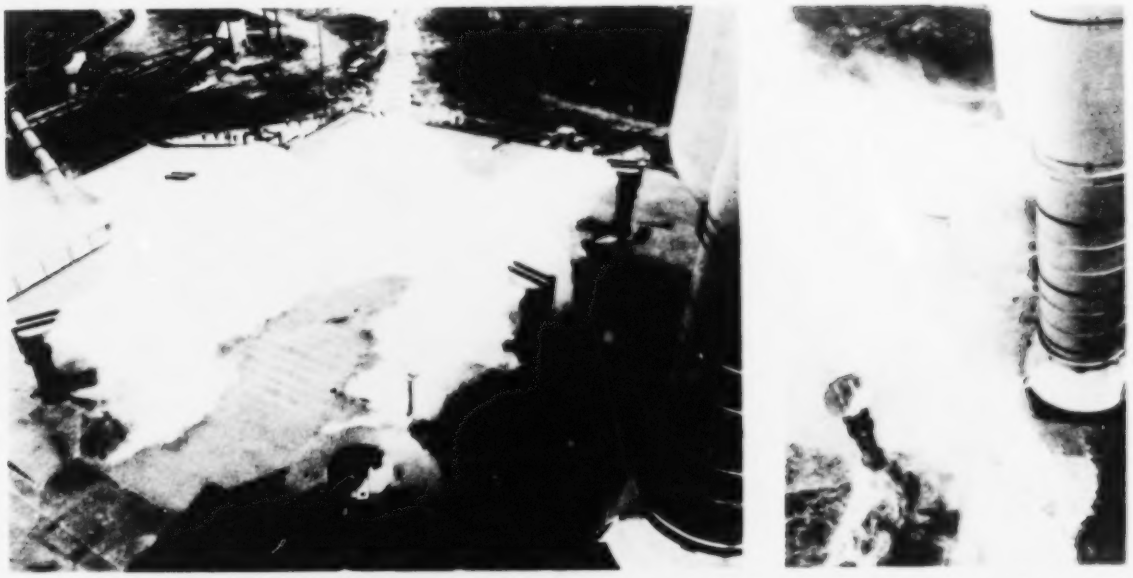
The *Lightning Mast* extends above the Fixed Service Structure and provides a "cone of protection" over the vehicle and pad structures. The 24-meter (80-foot) tall fiberglass mast is grounded by a cable which starts from a ground anchor 335 meters (1,100 feet) south of the Fixed Service Structure, angles up and over the lightning mast, then extends back down to a second ground anchor the same distance to the north. The mast functions as an electrical insulator, holding the cable away from the tower. The mast with its accompanying support structure extends 30 meters (100 feet) above the Fixed Service Structure.

A *Sound Suppression Water System* has been installed on the pad to protect the orbiter and its payloads from damage by acoustical energy reflected from the Mobile Launcher Platform during launch. The Shuttle orbiter, with its payloads in the cargo hold, is much closer to the surface of the Mobile Launcher Platform than was the Apollo spacecraft at the top of a Saturn V or Saturn IB rocket.

The sound suppression system



Astronauts Paul Weitz and Karol Bobko participate in the Emergency Egress Training on the slide wire at Pad 39A.



The rainbirds begin to place a cushion of water on the Mobile Launcher Platform to prevent reflection of acoustical energy from the platform's steel structure. Fresh water stored in the elevated tank flows through a valve network (upper left) to achieve proper pressure. It then flows through the giant pipes to the rainbirds.

includes an elevated water tank with a capacity of 1,135,550 liters (300,000 gallons). The tank is 88 meters (290 feet) high and is located on the northeast side of the pad. The water is released just prior to ignition of the Shuttle engines, and will flow through 2.1-meter (seven-foot) diameter pipes for about 20 seconds. Water pours from 16 nozzles atop the flame deflectors, and from outlets in the main exhaust hole in the Mobile Launcher Platform. By the time the solid rocket boosters ignite, a torrent of water will be flowing onto the Mobile Launcher Platform from six large quench nozzles, or "rainbirds," mounted on its surface.

The rainbirds are 3.6 meters (12 feet) high. The two in the center are 107 centimeters (42 inches) in diameter; the other four have a 76-centimeter (30-inch) diameter.

The peak rate of flow from all sources is 3,406,500 liters (900,000 gallons) of water per minute at nine seconds after liftoff.

Acoustical levels reach their peak when the Space Shuttle is about 91 meters (300 feet) above the platform, and cease to be a problem at an altitude of about 308 meters (1,000 feet).

Part of the Sound Suppression Water System is the Solid Rocket Booster Overpressure Suppression System. It alleviates the effect of a reflected pressure pulse which occurs at booster ignition. This pressure, without the suppression system, would exert significant forces on the wings and control surfaces of the orbiter.

There are two primary components to the system. A water spray system provides a cushion of water which is directed into the flame hole directly beneath each booster. This is supplemented by a series of water "hammocks" stretched across each hole, providing a water mass to dampen the reflected pressure pulse. Used together, this water barrier blocks the path of the reflected pressure wave, greatly decreasing its intensity.

In the event of an aborted mission, a Post-Shutdown Engine Deluge System is used to cool the aft end of the orbiter. It also controls the burning of residual hydrogen gas after the Shuttle's main engines have been shut down with the vehicle on the pad. There are 22 nozzles around the exhaust hole for the main engines within the Mobile Launcher Platform. Fed by a 15.2-centimeter (6-inch) diameter supply line, water flows at a rate up to 9,460 liters (2,500 gallons) per minute.

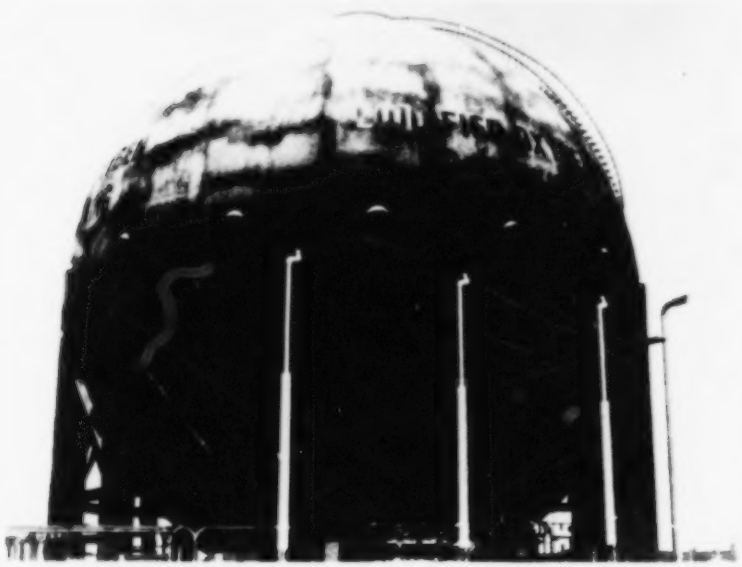
Propellant Storage Facilities are located at both pads. Liquid oxygen, used as an oxidizer by the orbiter's main engines, is stored in a 3,406,500-liter (900,000-gallon) tank located at the northwest corner of each launch pad. This ball-shaped vessel is a huge vacuum bottle which is designed to maintain the supercold temperatures of cryogenic propellants.

Liquid oxygen is transferred from the storage tank to the orbiter's external tank before flight by two pumps which supply 37,850 liters (10,000 gallons) per minute each.

The liquid hydrogen fuel for the orbiter's main engines is stored in a similar 3,218,250-liter (850,000-gallon) ball-shaped vessel located at the northeast corner of the pads.

Pumps are not required to move the liquid hydrogen from the storage tank to the orbiter's external tank during fueling operations. A small amount of liquid hydrogen is allowed to vaporize. This creates a gas pressure in the top of the tank that moves the extremely light fuel through the transfer lines.

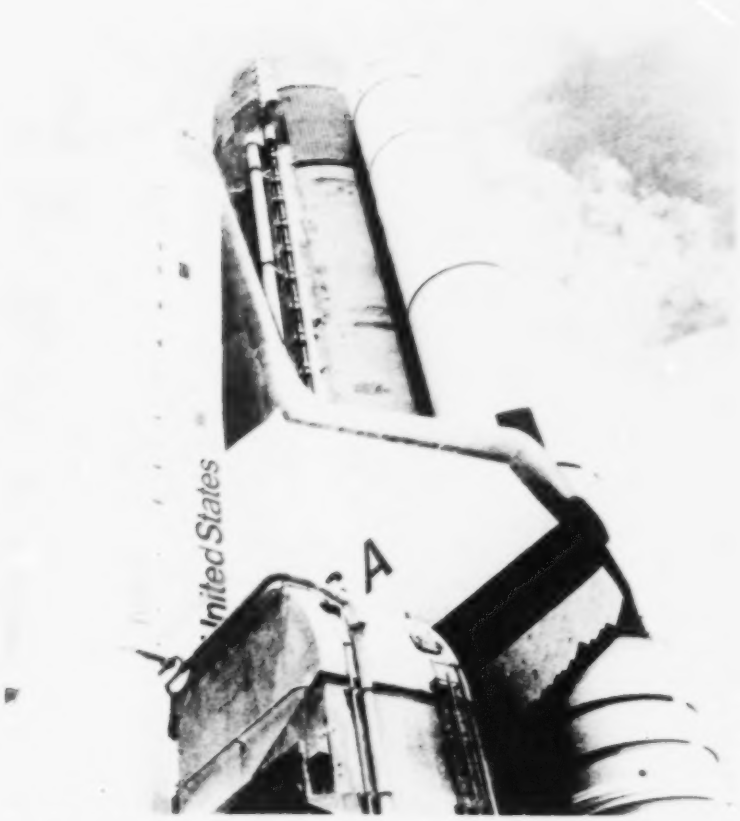
The vacuum-jacketed transfer lines carry the supercold propellants to the Mobile Launcher Platform, where they are fed from



Two large round vessels, one located near the pad perimeter on the east side and the other on the west, are actually giant dewars, or vacuum bottles. This one contains the supercold liquid oxygen, the other the liquid hydrogen which are burned as propellants in the orbiter's main engines.

the Tail Service Masts through the orbiter into the external tank.

Hypergolic Propellants used by the orbiter's Orbital Manauvering Engines and Attitude Control Thrusters are also stored at the pad, in well-separated areas. The fuel, monomethylhydrazine, is maintained in a facility located on the southwest corner of the pad area. Nitrogen tetroxide, an oxidizer, is stored in a similar facility located on the southeast corner. These propellants are fed by transfer lines to the Fixed Service Structure and continue to the Rotating Service Structure's Hypergolic Umbilical System, by which they are attached to the orbiter.



The Space Shuttle is poised for launch. The orbiter is connected to a tail service mast on each side which provides propellant loading umbilicals and establishes connections to ground support equipment.

Complex 39 is more than just a launch facility. A whole new era of transportation has come into being with the advent of the Space Shuttle, which can transport a variety of payloads into orbit.

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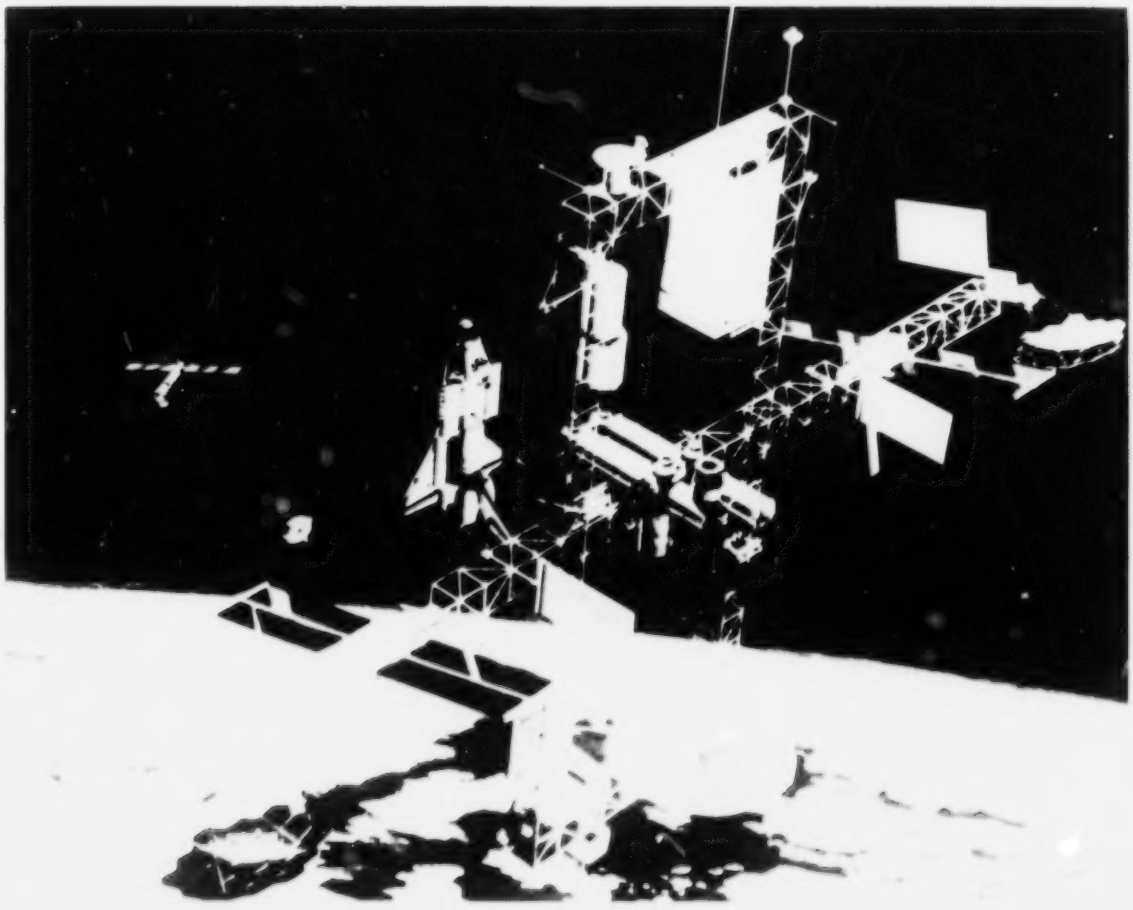

Space Station

NASA's launch vehicles, launch operations and facilities have been highly effective instruments of America's ambitious effort to explore and utilize the space environment. Over the years, these resources have been modified and upgraded to meet the growing complexity and reach of the nation's goals in space. As we move toward the 21st Century, new requirements and challenges will no doubt result in further refinements and the addition of more sophisticated resources and operations.

NASA

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Space Administration

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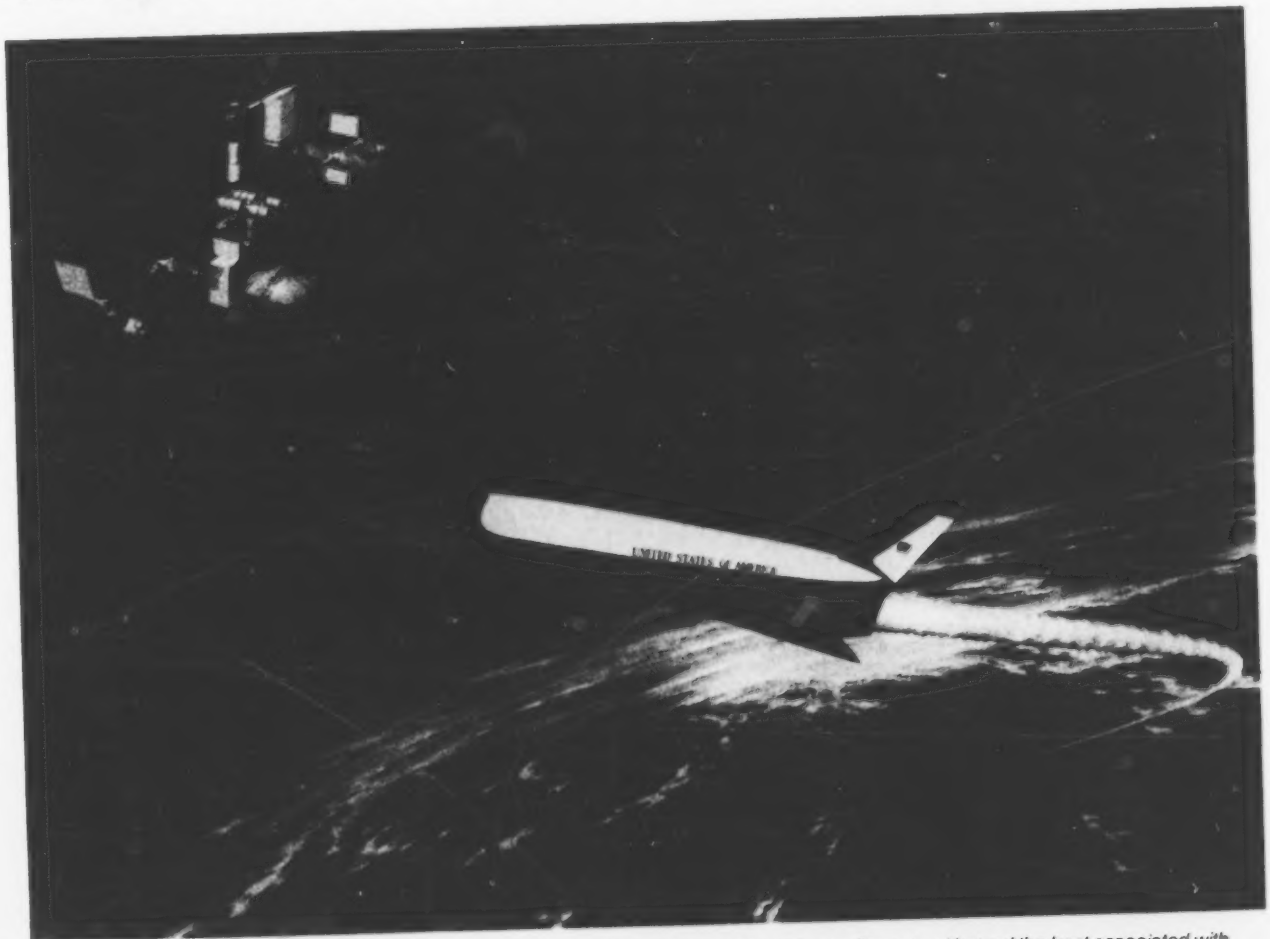
Space Administration

Information Summaries

PMS 027 (LaRC)
May 1987

What's New in NASA Aeronautics?



New high-temperature materials are being developed that will enable the National Aero-Space Plane to withstand the heat associated with high speed atmospheric flight. This vehicle, shown here as an artist's concept, would have advanced airbreathing engines. It would have the capability to take off horizontally from and land on conventional runways, accelerate to orbit, or cruise hypersonically in the atmosphere between Earth destinations. The National Aero-Space Plane program will provide the technology for space launch vehicles and hypersonic cruise vehicles.

New Concepts

Aeronautics, the science and art of flight through the atmosphere, involves designing, testing, building and operating aircraft. The National Aeronautics and Space Administration (NASA), through research and testing, develops new technology to improve aeronautics. Revolutionary new aircraft shapes will be seen in tomorrow's skies. Highly efficient airplanes will fly faster, higher and farther with dramatic operational abilities. The development of the National Aero-Space Plane represents a design that may typify the next generation of aircraft.

NASA's scientists and engineers are widely recognized for their past and current achievements in aeronautics research and technology development. Present aeronautics programs emphasize:

- Basic research and technology
- High-speed aircraft
- High-performance aircraft
- Subsonic aircraft, including transports and helicopters
- Propulsion systems
- Computers for design and testing

Three key aeronautics research centers—Ames at Moffett Field, California; Langley in Hampton, Virginia; and Lewis in Cleveland, Ohio—are supported by the Dryden Flight Research Facility in California, the Wallops Flight Facility on Virginia's Eastern Shore, other NASA centers and government agencies, universities and private industry.

New Shapes

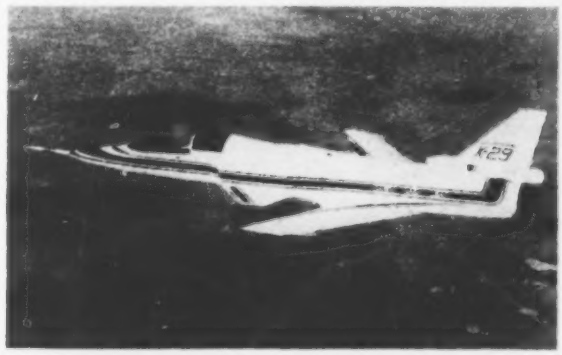
NASA conducts flight research on a wide spectrum of vehicles to explore basic aerodynamic phenomena, to develop and validate analysis and ground-based experiments, and to investigate concepts for new aircraft shapes. Much of this work is done at the Ames Research Center and at Ames-Dryden. Flight research is supplemented with scale-model and full-scale aircraft wind tunnel experiments.

Tilt Rotor. The XV-15 tilt-rotor aircraft combines the vertical flight capability of helicopters with the forward flight cruise speeds of fixed-wing turboprop airplanes. As its name implies, the tilt rotor changes its shape in flight. After taking off vertically, rotors on each wing tip tilt forward to transition from helicopter mode to airplane mode. The tilt concept is the basis of the Navy's V-22 Osprey full-scale development program and shows promise for civilian use also.

Tilt-Rotor aircraft offers all the advantages of conventional helicopters with the capability to lift off vertically. It can also fly like an airplane by rotating its engines down once airborne. The XV-15, shown here operating in the helicopter mode, can reach speeds up to 345 miles per hour.

X-Wing. The X-wing rotor can be stopped and started in flight, serving either as a rotor or a fixed-wing. It combines helicopter hover efficiency with fixed-wing high-speed cruise. In its fixed-wing configuration, X-Wing is powered by two turbofan engines.

Forward-Swept Wing. The X-29A aircraft revives the historic X-series of test aircraft to demonstrate an integrated set of improved technologies. The plane's unusual shape is possible, in part, because of improved materials and computerized digital flight control systems. These high-risk technologies are being proven in flight tests at Ames-Dryden. The X-29A may help shape future generations of high-speed tactical military aircraft by demonstrating better performance, longer range and improved maneuverability.



The futuristic X-29 Forward-Swept Wing aircraft took to the skies on February 4, 1985. The flight was the second in a series of four contractor acceptance flight tests. NASA and U.S. Air Force pilots will fly the aircraft after the government takes delivery of the X-29 following initial tests.

Propfan Test Assessment (PTA). The PTA program will use a Gulfstream II aircraft to evaluate in flight the new highly swept thin-bladed turboprop configuration that will initially power aircraft of the 150-passenger size in the early 1990s.

Flight Safety

Improved flight safety is a critical goal of aeronautics research. Storm hazards research, for example, has concentrated on the effects of rain, icing, low-altitude atmospheric disturbance, wind shear and clear air turbulence on aircraft.

The susceptibility to lightning of future aircraft is of great concern because of the growing use of all composite "skins" made of non-conductive plastics and the need for flight-critical, low-voltage electronic systems, like digital flight controls.

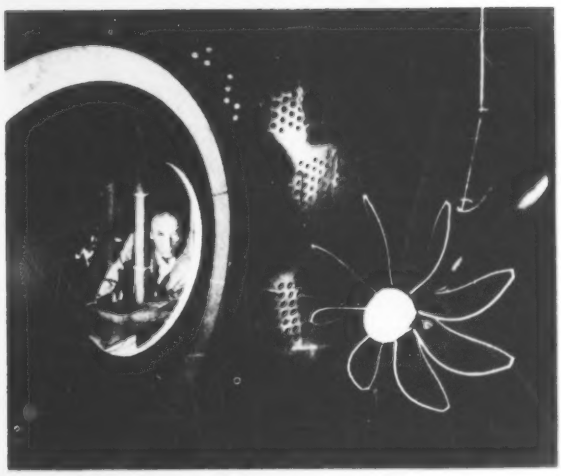
Intentional flights into thunderstorms provide NASA researchers with information about the physics (or characteristics) of lightning and its effects on airplanes. Knowledge of where lightning generally strikes and the path it takes over an airplane will allow engineeers to design aircraft with improved safety features.

NASA has documented many simulated civil aviation crashes. NASA, in cooperation with the Federal Aviation Administration, has deliberately crashed a remotely piloted Boeing 720 transport aircraft in a test to improve passenger survivability. Much valuable information was collected from this unique test.

Computer models are used to analyze these crash tests, which allow designers to more accurately predict what happens to an airplane structure during a crash. The models will also help researchers in investigations of other crash events.

Flight Efficiency

Propulsion Research



Materials and Structures

Aerodynamics

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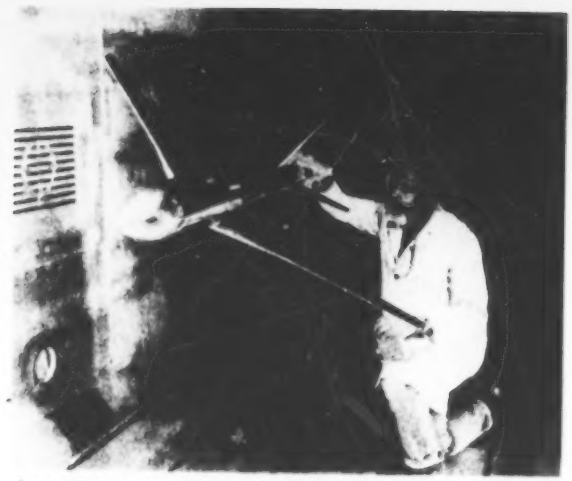
New Tools

Experimental Tools

aircraft. Tests are underway on models of an improved Space Shuttle, the Boeing 767, the X-29A and several general research aircraft.



A model is prepared for testing in the National Transonic Facility, a new kind of wind tunnel that uses cryogenic nitrogen gas at high pressure to test models of advanced aircraft and spacecraft designs.

How a Wind Tunnel Works. A wind tunnel is a tubelike structure or passage in which wind is produced, usually by a large fan, to flow over objects such as aircraft, engines, wings, rockets or models of these objects. A stationary object is placed in the test section of a tunnel and connected to instruments that measure and record airflow around the object and the aerodynamic forces that act upon it.

Wind tunnels are used extensively to test scale models and obtain information that verifies theory and performance estimates. Tunnels vary in size from those large enough to test a complete airplane or a large part of an airplane to those with a test section only a few inches square where models as small as the head of a match are tested.

Air flow in a wind tunnel is produced and conditioned in several ways to simulate flight at the speeds, altitudes and temperatures that would be encountered by particular kinds of aircraft. The speed of air flowing through a tunnel is usually expressed in terms of the speed of sound (760 mph at sea level). The ratio between the speed of air flow and the speed of sound is called a Mach number. At Mach 2, for example, the speed of a vehicle is twice the speed of sound, or 1,520 mph at sea level.

Speed ranges are divided into subsonic, transonic, supersonic and hypersonic. Subsonic is below Mach 0.8, the speeds flown by all light aircraft and most commercial transports. Speeds from Mach 0.8 to Mach 1.2 are transonic because the air flow over a vehicle crosses the speed of sound. The supersonic speed range is from Mach 1.2 to about Mach 5. Air flow above Mach 5 is called hypersonic. The Space Shuttle and Trans-Atmospheric Vehicle concepts travel at or through the hypersonic speed range.

Cryogenic temperatures as low as minus 300 degrees Fahrenheit are obtained in the new tunnel by evaporating liquid nitrogen into the tunnel circuit, creating nitrogen gas as the test medium.

Theoretical Tools. The Numerical Aerodynamic Simulation (NAS) program at the Ames Research Center provides the most powerful computational system in the world for aeronautical research and development. The heart of the NAS system is its super computer, which has a peak speed of one billion computations per second. The NAS program provides the computational power to make the most demanding aerodynamics computations ever attempted. It has high-speed processing networks with work stations, graphics features and satellite and land communications links between NASA's research centers. The new system will help solve major problems involving aerodynamics, structures, materials, weather and chemistry.

Computational fluid dynamics is emerging as a powerful tool for improved understanding of flow physics. It simulates conditions and flow phenomena that are difficult to measure physically. The Ames super computer will calculate real flow over complete aircraft and through internal passages of turbine engines.

Computational structural mechanics is being developed to provide accurate and efficient analyses of very complex airframe and engine structures. It is focused on advanced analytical methods and exploiting powerful parallel and multiprocessor computers. This capability will enable the design and development of lighter weight, more efficient aircraft through better structural designs and more effective uses of advanced materials.

New Goals

"Lasting U.S. aeronautical leadership will only be secured by the vigorous renewal of America's traditional strength: pioneering new technology."

—President's Office of Science and Technology Policy, 1985

This realization has caused the proposal of three new national goals for aeronautics research and development.

Subsonics. Develop the technology for an entirely new generation of fuel-efficient, affordable United States aircraft that will operate in a modernized national airspace system.

Supersonics. Develop technologies (especially for commercial aircraft) that will sustain supersonic cruise ability for long-distance efficiency.

Trans-Atmospherics. Develop the ability to routinely cruise and maneuver into and out of the atmosphere with takeoffs and landings from conventional runways, thereby providing flexible bases for global-range weapons delivery, reconnaissance and space support missions.

Collectively, these goals will focus national energies and creativity on new frontiers and opportunities that are vital for the success and leadership of the United States.

NASA Information Summaries

National Aeronautics and
Space Administration

PMS 001-A (KSC)
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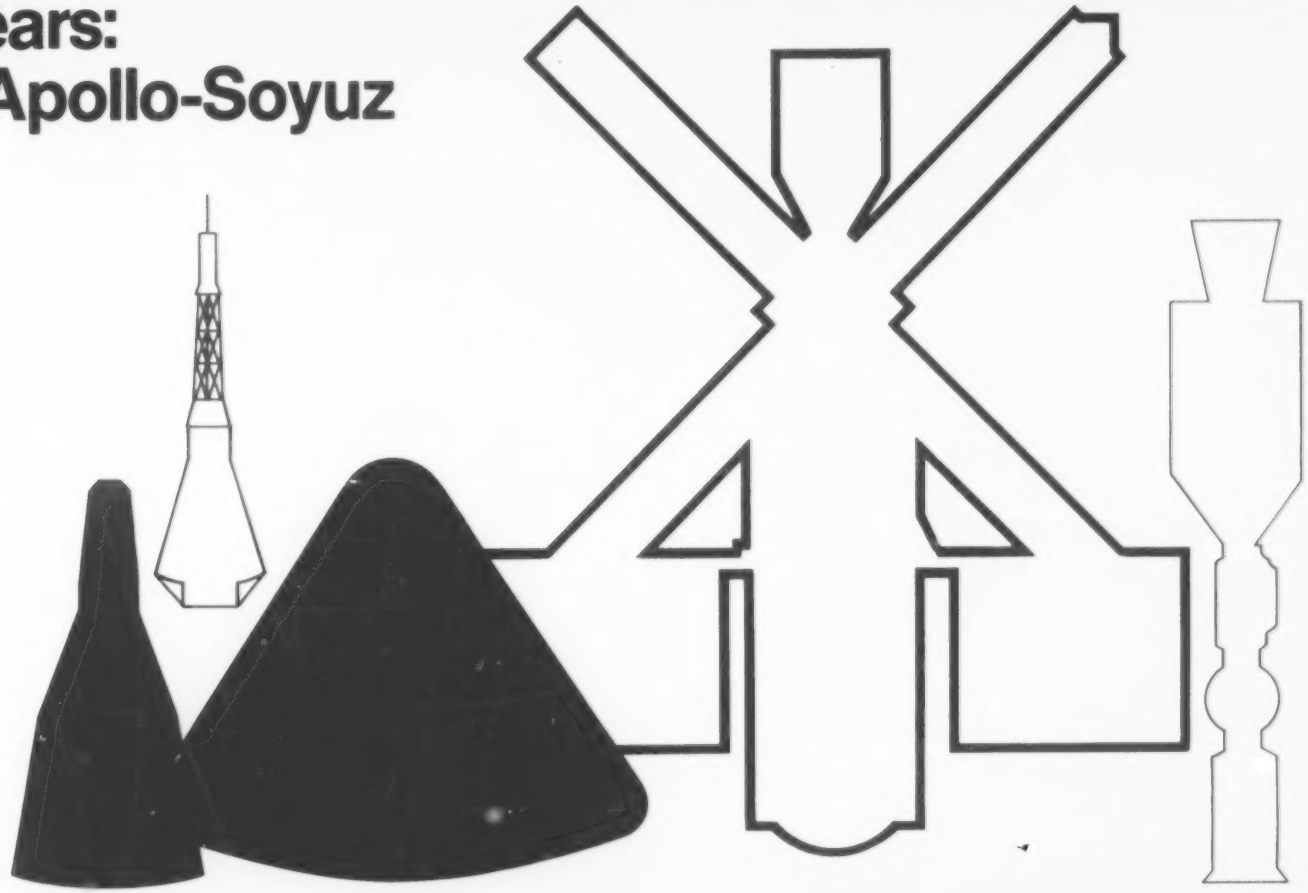
The Early Years: Mercury to Apollo-Soyuz



NASA

THE EARLY YEARS -
MERCURY TO APOLLO-SOYUZ

The United States manned space flight effort has progressed through a series of programs of ever increasing scope and complexity. The first Mercury launch from a small concrete slab on Complex 5 at Cape Canaveral required only a few hundred people. The launch of Apollo 11 from gigantic Complex 39 for man's first lunar landing engaged thousands. Each program has stood on the technological achievements of its predecessor. The complex, sophisticated Space Shuttle of today, with its ability to routinely carry six or more people into space, began as a tiny capsule where even one person felt cramped – the Mercury Program.

PROJECT MERCURY

Project Mercury became an official program of NASA on October 7, 1958. Seven astronauts were chosen in April, 1959, after a nationwide call for jet pilot volunteers. Project Mercury was assigned two broad missions by NASA–first, to investigate man's ability to survive and perform in the space environment; and second, to develop the basic space technology and hardware for manned space flight programs to come.

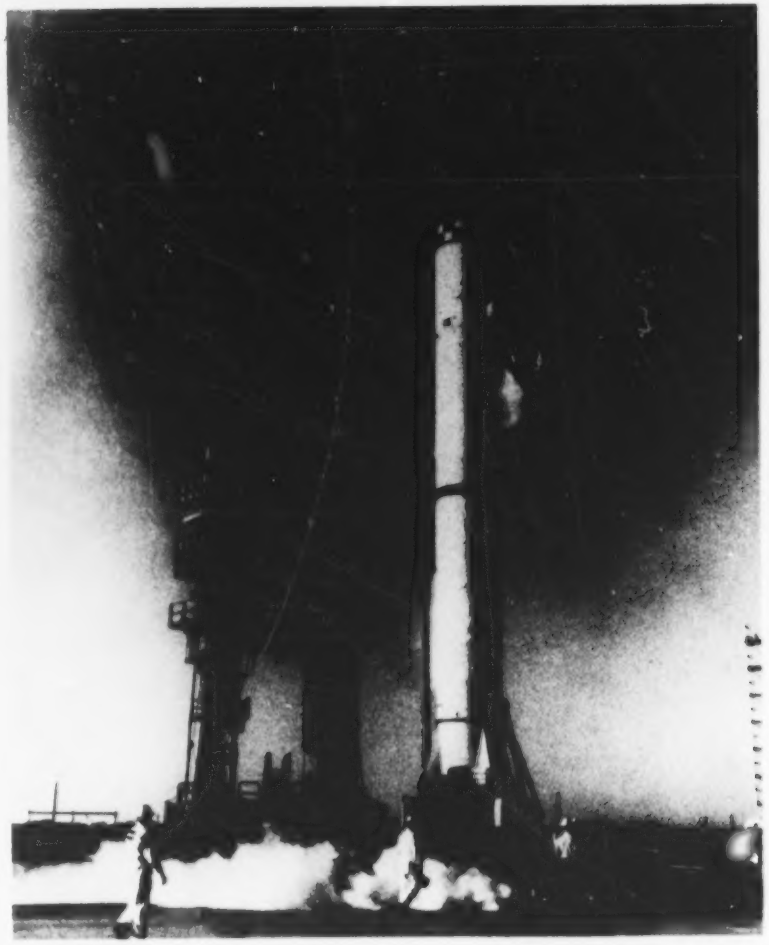
The one-man Mercury spacecraft was designed and built with a maximum orbiting mass of about 1,451.5 kilograms (3,200 pounds). Shaped somewhat like a bell, the craft was 189.2 centimeters (74.5 inches) wide across the bottom and about 2.7 meters (nine feet) tall. The astronaut escape tower added another 5.2 meters (17 feet) for an overall length of approximately 8 meters (26 feet) at launch. Two boosters were chosen–the Army Redstone with 346,944 newtons (78,000 pounds) thrust for the suborbital flights and the Air Force Atlas with 1,601,280 newtons (360,000 pounds) thrust for the orbital missions.

On May 5, 1961, Astronaut Alan B. Shepard, Jr., was launched from Complex 5 at Cape Canaveral by a Redstone Booster on the first U.S. manned space flight. His suborbital mission of 15 minutes took his Freedon 7 spacecraft 186.7 kilometers (116 miles) high into space.

On July 21, 1961, a Redstone booster hurled Astronaut Virgil I. "Gus" Grissom through the second and last suborbital flight in the Liberty Bell 7.

NASA then advanced to the Mercury-Atlas series of orbital missions. Another space milestone was reached on February 20, 1962, when Astronaut John H. Glenn, Jr., became the first American in orbit, circling the Earth three times in Friendship 7.

On May 24, 1962, Astronaut M. Scott Carpenter in Aurora 7 completed another three-orbit flight.



Preparations for the launch of Alan Shepard aboard a Redstone rocket from Complex 5 at Cape Canaveral.

NASA

Astronaut Walter M. Schirra, Jr., doubled the flight time in space and orbited six times, landing Sigma 7 in a Pacific recovery area. All prior landings had been in the Atlantic.

Finally, on May 15-16, 1963 Astronaut L. Gordon Cooper, Jr., completed a 22-orbit mission of 34 1/2 hours in Faith 7, triumphantly concluding the $392.6 million Project Mercury program.

PROJECT GEMINI

The Gemini spacecraft was designed to be piloted by two astronauts and consisted of two major portions—the re-entry module and the adapter module. Only the re-entry module, containing the life-support cabin where the astronauts rode, returned to Earth. It was comprised of a double-walled inner shell around the crew's pressurized compartment, with an outer shell as the craft's external hull. The adapter module had two separate sections, so that Gemini, as launched, was actually a three-part structure. One purpose of the two-part adapter module was to fit the narrow Gemini capsule to the broader top of the booster. It also contained attitude controls, propellant tanks, electrical components and other support equipment. The section adjacent to the crew's re-entry module included two sets of engines—retrorockets and space-maneuvering thrusters.

An Atlas rocket launched Astronaut John Glenn in a Mercury spacecraft from Complex 14 at Cape Canaveral on NASA's first Earth orbital flight.

The Gemini spacecraft was similar to but heavier than the Mercury, and the Redstone and Atlas boosters lacked the power to place it in orbit. A modified version of the military Titan II was chosen as the Gemini Launch Vehicle. With a first stage thrust of 1,912,640 newtons (430,000 pounds), the rocket used hypergolic, or self-igniting, propellants, which were non-explosive and an added astronaut safety factor. The Titan II rocket was three meters (10 feet) wide and 27.1 meters (89 feet) long. The combined Gemini-Titan stood 32.9 meters (108 feet) high.

Chosen for Gemini's orbital rendezvous and docking was the Agena-D target vehicle, a modified version of the Agena-B second stage that, with Thor or Atlas boosters, had orbited many satellites and launched Mariner and Ranger space probes. The Agena's stop-and-restart engine, capable of cutoff and reignition at least four times, was important for planned maneuvers with the Gemini capsule. The Agena-D was 9.75 meters (32 feet) long and 1.5 meters (five feet) in diameter, with a cylindrical shape.

There was a total of 10 manned Gemini flights, four of which rendezvoused with an Agena stage. A rendezvous mission generally called for launching an Atlas/Agena target vehicle from Complex 14 at Cape Canaveral, then the Gemini liftoff from Complex 19.

The Agena was propelled into a circular orbit 298 kilometers (185 miles) up, after which precise velocity and trajectory elements were calculated. The Gemini would then be launched into a lower orbit. By travelling a shorter distance it would catch up with the Agena.

When the distance between the vehicles was 402 kilometers (250 miles) radar was switched on. As the gap closed to 80.5 kilometers (50 miles), the astronauts picked up the Agena's flashing beacon and took manual control of Gemini to maneuver it into position.

During rendezvous maneuvers the relative speed between the vehicles was cut to less than 3.2 kilometers (2 miles) per hour, so that when docking, their noses touched gently.

On contact, the Gemini's narrow end entered the Agena's target docking adapter. The adapter's latches clamped shut to prevent the two vehicles from slipping apart. Then a motorized Agena unit pulled the Gemini inward. Matching electrical contacts met and gave the astronauts direct control of the Agena's onboard equipment.

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From the first unmanned Gemini flight on April 8, 1964, to the final manned flight ending November 15, 1966, Gemini flight time totaled 974 hours 37 minutes 42 seconds. Of this, 969 hours 51 minutes 26 seconds were manned. The astronauts spent a total of 12 hours 12 minutes in extravehicular activity (EVA, or "space-walk activities").

The highest altitude reached by the manned Gemini spacecraft—a world's record at that time—was 1,372.8 kilometers (853 miles) during the Gemini 11 mission.

Orbital rendezvous was accomplished 10 times; docking 9 times. Docking was first accomplished on March 16, 1966, during Gemini 8, and was another Gemini "space first." Also, Gemini and Agena, linked by a tether, orbited Earth for over four hours in a station-keeping exercise aimed at saving maneuvering fuel. Project Gemini was undertaken at a cost of $1.3 billion.

PROJECT APOLLO

Initial planning for a rocket having a high payload capability began in April, 1957. In August, 1958, studies concluded that a clustered booster of 6,672,000 newtons (1.5 million pounds) thrust was feasible, and the research and development effort began. Initial results validated the engine clustering technique, using existing hardware. The planned vehicle was designated the Saturn I.

Rocketdyne, a division of North American Rockwell Corporation (now Rockwell International), uprated the Thor-Jupiter engine and increased its thrust, thus developing the 889,600-newton (200,000-pound) thrust H-1 engine. Concurrently, from advanced studies, the heavy thrust F-1 engine was conceived, and subsequently used as the power plant for even larger boosters.

In July, 1960, NASA first proposed publicly a post-Mercury program for manned flight and designated it Project Apollo. The Apollo goals envisioned at the time were Earth-orbital and circumlunar flights of a three-man spacecraft.

During 1960, Douglas Aircraft Company (now McDonnell Douglas) was selected to build the Saturn I second stage (S-IV) and Rocketdyne was chosen to develop the hydrogen-fueled J-2 engine for future upper stages of the Saturn vehicles.

On May 25, 1961, President John F. Kennedy proposed to Congress that the United States accelerate its space program, establishing as a national goal a manned lunar landing and return by the end of the decade. In his report to Congress President Kennedy said:

"Now is the time . . . for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth."

The Agena Target Docking Vehicle as seen from the Gemini 12 spacecraft during rendezvous.

Ten Gemini Earth orbital missions were launched from Complex 19 using the Titan II rocket.

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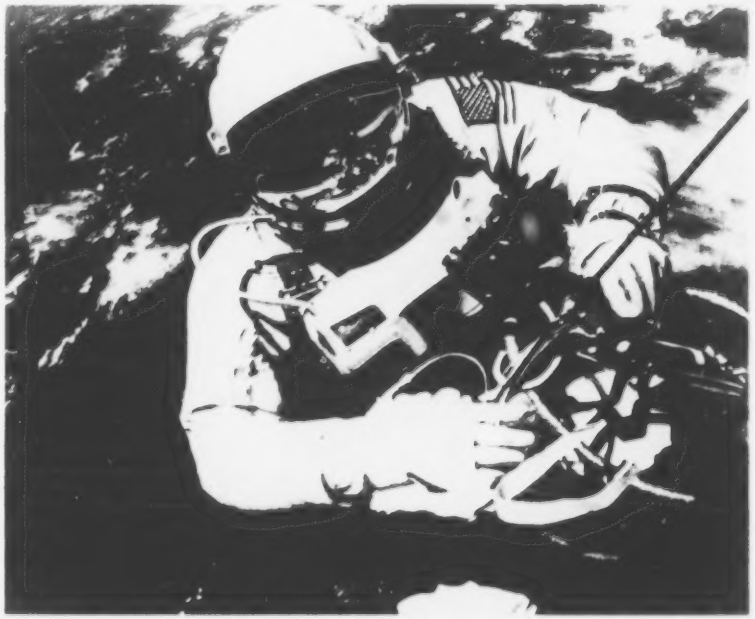
With endorsement by Congress, the national objective of manned lunar exploration created an immediate need for a considerably more powerful booster.

In January, 1962, NASA announced the planned development of the largest rocket vehicle ever to fly, the mammoth Saturn V. Contracts were awarded to the Boeing Company for the first stage and North American Rockwell for the second stage. The third stage, called the S-IVB, already was under development by Douglas Aircraft Corporation, with its first flights scheduled on top of the Saturn I.

The Saturn V first stage was to use a cluster of five F-1 engines that would generate 33,360,000 newtons (7.5 million pounds) of thrust. The second stage utilized a cluster of five J-2 engines that developed a combined thrust of 4.4 million newtons (one million pounds). The third stage was powered by a single J-2 engine with 889,600 newtons (200,000 pounds) thrust capability. IBM already had started the development of the instrument unit for the Saturn V.



Gemini 4 Astronaut Ed White made America's first space walk on June 3, 1965, during the third orbit of a four-day mission.

Later in 1962, NASA announced it was developing the Saturn IB, which combined the first stage of the Saturn I and the third stage of the Saturn V. This vehicle would perform Earth orbital tests of the Apollo spacecraft.

On August 9, 1961, the Massachusetts Institute of Technology was selected to develop the Apollo spacecraft guidance and navigation system. Three and a half months later, NASA selected North American Rockwell for the Apollo spacecraft command and service module program.

In mid-July, 1962, NASA selected the lunar orbital rendezvous mode for the lunar mission. This called for development of a two-man lunar module, to be used for landing on the Moon and returning to lunar orbit. On November 7, 1962, Grumman Aircraft Engineering Corporation was selected to design and build the lunar module.

The first phase of the Saturn launch vehicle program was completed in 1965. In ten flights of the Saturn I, ten were successful—an unprecedented record in rocket development. Much technology was proven in the Saturn I program. The rocket guidance system was developed, the concept of clustered rocket engines was validated, and more experience was gained in the use of liquid hydrogen as a fuel. Liquid hydrogen, previously used only in the Centaur stage, provides approximately 40 percent greater power than earlier fuels.

The new Saturn IB launch vehicle was successfully flown three times in three attempts in 1966. Two of these flights carried spacecraft which satisfactorily completed Apollo command and service module requirements for Earth orbital operations.

On January 27, 1967, tragedy struck the space program when a fire erupted inside an Apollo spacecraft during ground testing at Complex 34, resulting in the deaths of Astronauts Virgil Grissom, Edward White, II, and Roger Chafee. After two and a half months of investigation, involving 1,500 people, the Board of Inquiry determined the most likely cause of the accident. Electrical arcing from the spacecraft wiring in a near-total oxygen environment induced a flash fire. After an extensive investigation by an Accident Review Board, NASA followed up with detailed descriptions of corrective actions, schedule modifications, and cost estimates necessary to get the program back on track.

On November 9, 1967, the first flight test of the Apollo/Saturn V space vehicle was successfully accomplished. Designated Apollo 4, the unmanned flight demonstrated excellent performance by the previously unflown first and second stages. It proved the restart-in-orbit capability of its third stage, the ability of the Apollo spacecraft to re-enter Earth's atmosphere at lunar mission return speeds, the overall performance of the integrated space vehicle, and the operational readiness of Kennedy Space Center Launch Complex 39. All mission objectives were met. The Saturn V placed a total

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weight of 126,418 kilograms (278,699 pounds) in orbit after a near-perfect countdown. The spacecraft heat shield performed satisfactorily during the 39,912 kilometer per hour (24,800 mph) plunge into Earth's atmosphere.

During the two-day Apollo 5 mission in January, 1968, Lunar Module systems and structural performance of the spacecraft were demonstrated and all test objectives were met. This included two firings of both the ascent and descent propulsion systems. Post-flight analysis determined the Lunar Module to be ready for manned Earth orbital missions. Apollo 5 was launched aboard a Saturn IB from Launch Complex 37 on January 22, 1968.

On April 4, 1968, Apollo 6 became the second unmanned Saturn V mission to demonstrate launch vehicle and spacecraft performance. After its launch from Complex 39, vertical oscillations, or "Pogo" effect, occurred in the first stage, and some small propellant lines ruptured in upper stages. Otherwise, the mission was considered very successful.

The first manned Apollo launch, Apollo 7, was on a Saturn IB, and was the last launch from Complex 34. All subsequent Apollo launches were from Complex 39. Lifting off the pad on October 11, 1968, it was to become an 11-day flight. Apollo 7 ended with a precise re-entry and splashdown on October 22, and was called a "101 percent successful" mission. Manned by Astronauts Walter Schirra, Don Eisele, and Walt Cunningham, the spacecraft's performance in space was flawless, including eight firings of the spacecraft's primary propulsion system and the first live television broadcast from a manned space vehicle.

Apollo 8, with Astronauts Frank Borman, William Anders, and James Lovell, Jr., lifted off on December 21, 1968. It was history's first manned flight from Earth to another planetary body. In 147 hours, Apollo 8 took its crew on a faultless, half-million-mile space flight, including ten lunar orbits, lunar and Earth photography and live television broadcasts.

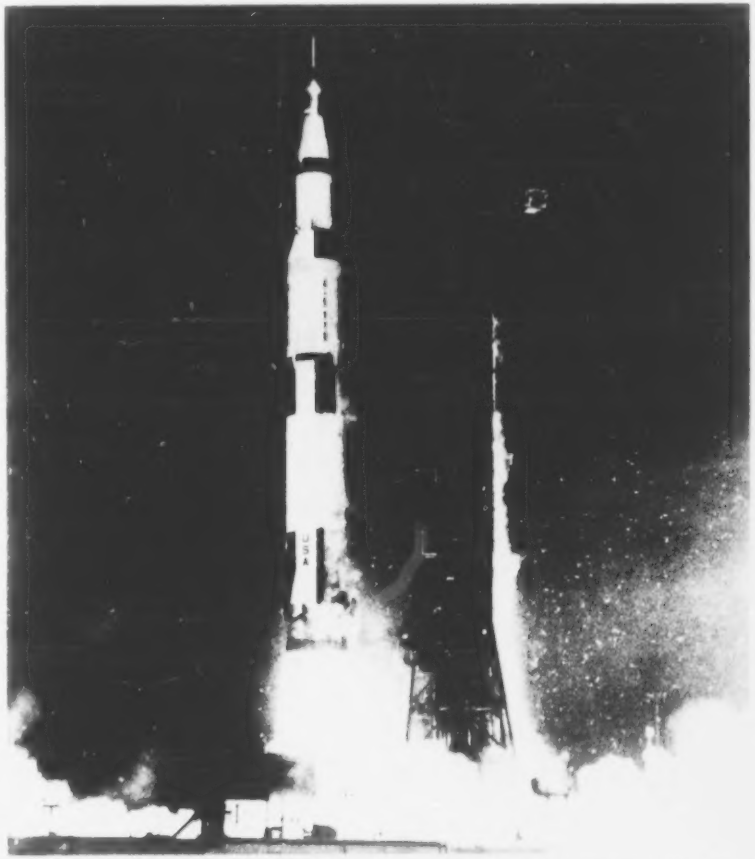
Apollo 9 splashed down in the Atlantic Ocean, north of Puerto Rico on March 13, 1969, after a 10-day, 9.6-million-kilometer (6-million-mile) Earth orbital mission. All major mission objectives were met in the first five days of flight. Apollo 9 was the first all-up manned flight of the Apollo/Saturn V space vehicle, first manned flight of the Lunar Module, and first Apollo extravehicular activity. It included rendezvous and docking, live television, photographic surveys of Earth, and observation of the Pegasus II satellite and the planet Jupiter. This was the fourth Saturn V on-time launch (11:00 a.m. EST).

Apollo 10 successfully completed man's second lunar orbital flight, passing within 14.5 kilometers (nine miles) of the lunar surface in a dress rehearsal for the actual lunar landing mission. Launched on May 18, from pad 39B, Apollo 10 spent nearly 62 hours (31 revolutions) in lunar orbit, sent 19 live color TV transmissions, and splashed down within 6,400 meters (7,000 yards) of its primary recovery ship in the Pacific Ocean, eight days and three hours after liftoff.

Apollo 11 attained the national goal, set by President Kennedy in 1961, of landing men on the Moon and returning them safely to Earth within the decade of the 1960's. The mission was launched precisely on time from Kennedy Space Center at 9:32 a.m. EDT, July 16, by a Saturn V. The Lunar Module touched down in the Moon's Sea of Tranquility at 4:18 p.m. EDT, July 20, and Commander Neil Armstrong stepped onto the lunar surface

A Saturn IB rocket lifts Apollo 7 into Earth orbit from Complex 34 at Cape Canaveral. It was the first manned Apollo flight.

at 10:56 p.m. EDT that evening, followed by Lunar Module pilot Edwin E. Aldrin, Jr. Astronaut Michael Collins, the Command Module pilot, orbited above, conducting scientific experiments and taking photography. Their activities were viewed live around the world by the largest television audience in history. The returning spacecraft splashed down in the Pacific southwest of Hawaii at 12:51 p.m. EDT, July 24, after a flight of 8 days 3 hours 19 minutes. Scientific instruments were left on the Moon, and samples of the Moon's soil and rocks, along with still and motion pictures were brought back to Earth.



The Saturn V, largest and most powerful rocket vehicle ever built, lifting off from Complex 39 at the Kennedy Space Center.

Four months after the Apollo 11 landing, Apollo 12 repeated the journey, landing and exploring at the Ocean of Storms. The Apollo 12 mission, launched November 14, 1969, demonstrated the ability to land at a selected point. The astronauts installed the first Apollo Lunar Surface Experiments Package on the surface for continued science reporting after the departure of the astronauts. Two extravehicular activity periods were completed, which included experiments engagement, field geology investigations and inspection of the Surveyor III spacecraft launched in 1967.

Apollo 13 was launched April 11, 1970, to land on the Fra Mauro upland area of the Moon. An explosion of the Service Module oxygen tank at 10:13 p.m. EST, April 13, caused a power failure of the Command and Service Module electrical system which prevented the lunar landing. The crew used the Lunar Module as their command post and living quarters for the remainder of the flight. The Lunar Module descent engine provided propulsion to make corrections in the flight path which sent the spacecraft around the Moon on a free-return trajectory, for re-entry and splashdown in the Pacific Ocean on April 17.

The Apollo 13 Review Board announced on June 30 that a short circuit in the electrical insulation in the spacecraft oxygen tank Number 2 caused failure of the tank. The Board recommended the command and service module system be modified to eliminate potential combustion hazards in high-pressure oxygen containers.

Apollo 14 was scheduled to accomplish the mission planned for Apollo 13. The spacecraft was launched at 4:03 p.m. EST Sunday, January 31, 1971, and the Lunar Module touched down on the Moon at 4:17 p.m. EST February 5, within 18.4 meters (60 feet) of the targeted point on the Fra Mauro formation. The astronauts successfully carried out two periods of extravehicular activity on the lunar surface, the first for 4 hours 50 minutes and the second for 4 hours 35 minutes, totaling 9 hours 25 minutes. They successfully deployed and activated the experiments package, the second set of geophysical instruments to transmit data on the Moon's interior and exterior environment to Earth. In addition, they collected 43.5 kilograms (96 pounds) of lunar rocks and soil, which included two rocks weighing 4.5 kilograms (10 pounds) each, the largest obtained to date. After spending 33 1/2 hours on the Moon, the Lunar Module lifted off the surface at 1:47 p.m. EST Saturday, February 6, 1971. The return flight was normal and the spacecraft landed in the South Pacific Ocean at 4:05 p.m. EST February 9, 1971.

The fourth lunar landing mission, Apollo 15, was launched Monday, July 26, 1971. Modifications to the spacecraft permitted longer lunar surface stay time and additional scientific instruments in lunar orbit. On July 30, at 6:16 p.m. EDT, the astronauts landed at the Hadley Apennine site. During

their 66-hour 55-minute stay on the Moon they explored the lunar surface, riding the first Lunar Rover vehicle, for a total of 18 hours 36 minutes; collected approximately 77 kilograms (170 pounds) of surface samples; deployed geophysical instruments; and described geological features. In the Command Module, extensive scientific experiments were conducted while orbiting the Moon, including the operation of two cameras and gamma ray and X-ray sensors mounted on the Service Module. After 74 lunar revolutions and ejection of a subsatellite, the spacecraft began its homeward journey. Camera film canisters were retrieved by the Command Module pilot from outside the spacecraft during the trans-Earth coast. The Pacific Ocean landing was made on August 7, 1971.

Apollo 16, the fifth lunar landing mission, was launched April 16, 1972. In all, the astronauts spent nearly 20 1/4 hours outside the Lunar Module--a new record. In lunar orbit, the Command Module pilot operated a complex array of scientific instruments; two lunar mapping cameras observed geological features on the surface. Once again, a scientific subsatellite was placed in lunar orbit before the trans-Earth maneuver was performed. On the Earthbound trip the film canisters were retrieved from the lunar cameras outside the Command Module. The spacecraft splashed down in the Pacific Ocean on April 27. The astronauts had returned approximately 95.3 kilograms (210 pounds) of Moon rocks and soil samples to Earth from the Descartes highlands.

The final Apollo mission, Apollo 17, was launched December 7, 1972. On the 12-day mission the astronauts explored the Taurus-Littrow landing site, emplaced geophysical instruments, and collected over 108 kilograms (240 pounds) of samples. The total surface time outside the Lunar Module was 22 hours and 4 minutes, exceeding by almost two hours the previous record held by Apollo 16. The Command Module pilot again operated scientific instruments and cameras in lunar orbit; then retrieved the camera film during a 1-hour, 6-minute space walk en route back to Earth. Splashdown in the Pacific occurred December 19, 1972.

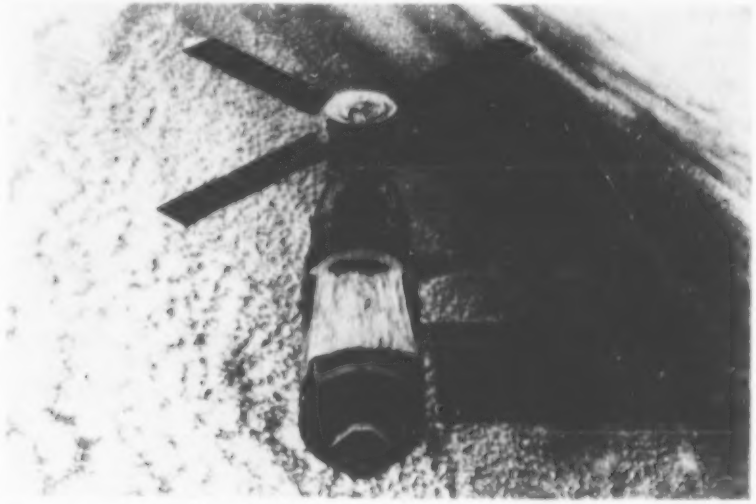
Apollo program costs were approximately $25 billion.*

SKYLAB

There were four launches in the Skylab Program from Complex 39 at the Kennedy Space Center. The first launch was on May 14, 1973 at 1:30 p.m. A two-stage Saturn V placed the unmanned 90-metric ton (100-ton) Skylab space station in a 434.5-kilometer (270-mile) Earth orbit. As the rocket accelerated past 7,620 meters (25,000 feet), atmospheric drag began

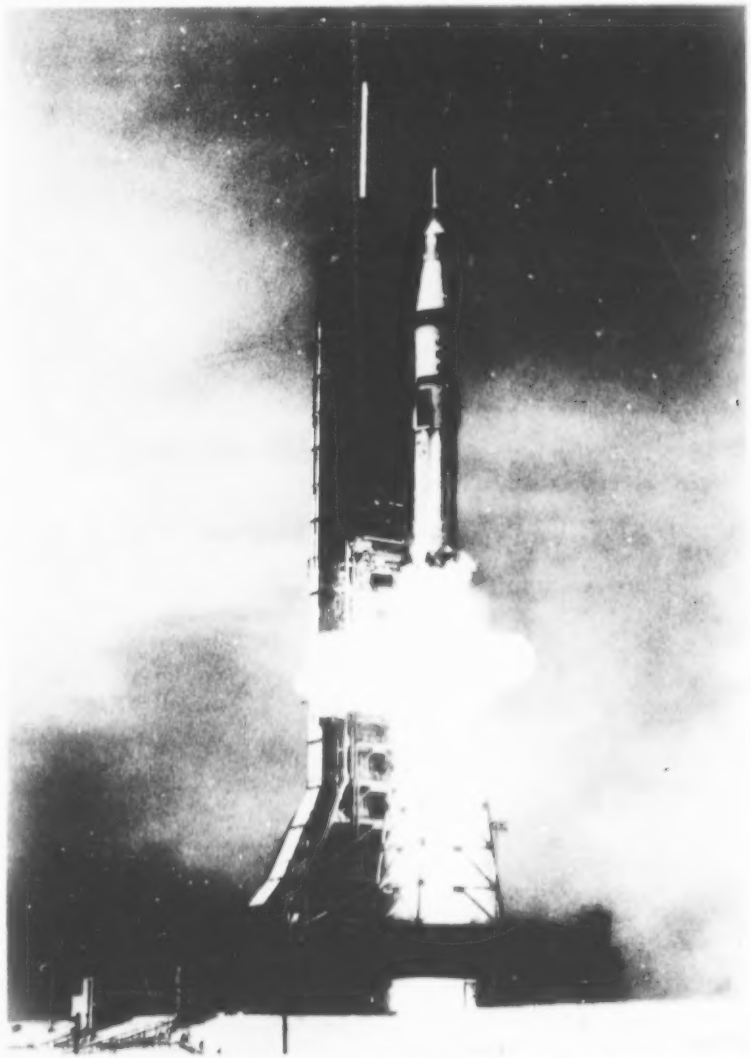
*Includes rockets, engines, spacecraft, tracking and data acquisition, operations, operations support, and facilities.

Standing on the Moon, Apollo 15 Astronaut James Irwin salutes the flag alongside the Lunar Module and Lunar Rover.



Skylab, orbiting 270 miles above the Earth, was both workshop and home for three teams of astronauts. The Skylab space station was inhabited for a total of 171 days.

NASA



The three manned Skylab missions and the Apollo-Soyuz Test Project (ASTP) were launched from Pad 39B using the Saturn Ib rocket.

third mission was extensive observation and photography of Comet Kohoutek. This mission of over 84 days increased the previous record length in space set by the second Skylab crew by about 50 percent.

The Skylab space station re-entered the Earth's atmosphere at 12:37 p.m. EDT, July 11, 1979, near southeastern Australia. After over six years in space, the demise of the orbital workshop came on its 34,981st orbit. Skylab program costs totaled $2.6 billion.

APOLLO-SOYUZ TEST PROJECT (ASTP)

The $250 million Apollo-Soyuz mission was successfully completed on July 24, 1975. In a fitting conclusion to the Apollo flights, operation of the Saturn IB launch vehicle was flawless and the spacecraft had the fewest inflight anomalies of any Apollo flown. The scientific payload of 28 experiments supplied a rich harvest of data in many fields.

Both the Soyuz and Apollo spacecraft were launched on July 15, 1975; the Apollo lifted off approximately 7-1/2 hours after Soyuz. The Soyuz maneuver to the planned orbit for docking was successfully completed over Europe on the 17th orbit, at an altitude of 222 kilometers (138 miles.) The Apollo crew completed the rendezvous sequence as planned; docking with Soyuz was accomplished on July 17 when the Apollo spacecraft was gradually piloted toward the orbiting Soyuz. During the next two days, the crews accomplished four transfer operations between the two spacecraft and completed five scheduled experiments. In addition, the crews provided television views of the interior of the two spacecraft, and demonstrated various aspects of space operations.

This mission marked the first time that voice, TV, and telemetry were relayed between an orbiting Apollo spacecraft and the ground via the ATS-6 communications satellite. This new technique more than tripled the communications coverage otherwise available. Following the first undocking, a joint solar eclipse experiment was performed. Then Apollo performed a second docking, this time with the Soyuz apparatus locking the two spacecraft together. The final undocking occurred on July 19. The two spacecraft were moved to a station-keeping distance and a joint ultraviolet absorption experiment was performed, involving a complicated series of orbital maneuvers. Afterward Apollo entered a separate orbit, and unilateral activities were conducted by both the Soyuz and Apollo crews. The Soyuz landed safely on July 21, after six mission days, and the Apollo flight was successfully concluded on July 24, 1975, nine days after launch. The primary objectives of the program were met, including rendezvous, docking, crew transfer, and control center-crew interaction. All objectives of the scientific experiments were completed. The unilateral portion of the Apollo flight was a full scientific mission in itself, and yielded significant results.

MANNED SPACECRAFT

Mercury

Height: 2.9 meters (9.5 feet)
Maximum Diameter: 1.9 meters (6.2 feet)
Weight: 1,451 kilograms (3,200 pounds)
Habitable Volume: 1.02 cubic meters (36 cubic feet)

Gemini

Height: 5.5 meters (18 feet)
Maximum Diameter: 3 meters (10 feet)
Weight: 3,402 kilograms (7,500 pounds)
Habitable Volume: 1.56 cubic meters (55 cubic feet)

Apollo

Command Module — Height: 3.5 meters (11.4 feet)
Maximum Diameter: 3.9 meters (12.8 feet)
Weight: 5,830 kilograms (12,850 pounds)
Habitable Volume: 5.95 cubic meters (210 cubic feet)

Service Module — Height: 7.5 meters (24.6 feet)
Diameter: 3.9 meters (12.8 feet)
Weight: 24,550 kilograms (54,120 pounds)

Lunar Landing Module — Height: 7 meters (23 feet) legs extended
Diameter: 9.4 meters (31 feet) across legs
Weight: 3,900 kilograms (8,600 pounds)
Habitable Volume: 4.5 cubic meters (158.8 cubic feet)

Skylab Space Station

Total Cluster (Orbital Workshop, Apollo Command/Service Modules, Airlock, Multiple Docking Adapter, Apollo Telescope Mount, Solar Arrays, Payload Shroud)

Length: 35.5 meters (117 feet)
Maximum Diameter: 27.5 meters (90 feet) across Solar Arrays
Weight: 90,606 kilograms (199,750 pounds)
Habitable Volume: 360 cubic meters (12,711 cubic feet)

Workshop Only

Length: 14.6 meters (48 feet)
Diameter: 6.7 meters (22 feet)
Weight: 35,380 kilograms (78,000 pounds)
Habitable Volume: 275 cubic meters (9,710 cubic feet)

NASA

MANNED SPACE LAUNCH VEHICLES

Mercury-Redstone

Height: 25.3 meters (83 feet)
Weight: 28,123 kilograms (62,000 pounds)
Thrust: 346,944 newtons (78,000 pounds)
Propellants: ethyl alcohol, water, liquid oxygen

Mercury-Atlas

Height: 29 meters (95 feet)
Weight: 117,900 kilograms (259,920 pounds)
Thrust: 1,601,280 newtons (360,000 pounds)
Propellants: RP–1 (refined kerosene), liquid oxygen

Gemini-Titan II

Height: 32.9 meters (108 feet)
Weight: 136,080 kilograms (300,000 pounds)
Thrust: 1,912,640 newtons (430,000 pounds)
Propellants: unsymmetrical dimethylhydrazine (UDMH), nitrogen tetroxide

Apollo-Saturn IB

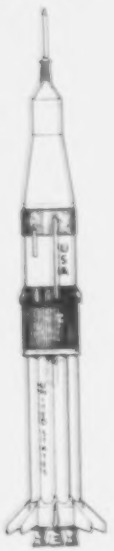
Height: 68 meters (223 feet)
Weight: 544,320 kilograms (1,200,000 pounds)
Thrust: 7,116,800 newtons (1,600,000 pounds)
Propellants: First Stage – RP–1 (refined kerosene), liquid oxygen
Second Stage – liquid hydrogen, liquid oxygen

Apollo-Saturn V

Height: 110.6 meters (363 feet)
Weight: 2,812,320 kilograms (6,200,000 pounds)
Thrust: First Stage – 33,360,000 newtons (7,500,000 pounds)
Second Stage – 4,448,000 newtons (1,000,000 pounds)
Third Stage – 889,600 newtons (200,000 pounds)
Propellants: First Stage – RP–1 (refined kerosene), liquid oxygen
Second Stage – liquid hydrogen, liquid oxygen
Third Stage – liquid hydrogen, liquid oxygen

APOLLO-SATURN V

APOLLO-SATURN IB



GEMINI-TITAN II

MERCURY-ATLAS

MERCURY-REDSTONE

96

Program [1]	Date(s)/Recovery Ship [2]	Crew	Mission Duration [3]	Remarks [4]
MERCURY				
Mercury Redstone 3 (Freedom 7)	May 5, 1961 Lake Champlain (A)	Navy Comdr. Alan B. Shepard, Jr.	0:15:22	suborbital
Mercury Redstone 4 (Liberty Bell 7)	July 21, 1961 Randolph (A)	USAF Maj. Virgil I. Grissom	0:15:37	suborbital
Mercury Atlas 6 (Friendship 7)	Feb. 20, 1962 Noa (A)	Marine Lt. Col. John H. Glenn	4:55:23	3 orbits
Mercury Atlas 7 (Aurora 7)	May 24, 1962 Pierce (A)	Navy Lt. Comdr. Scott Carpenter	4:56:05	3 orbits
Mercury Atlas 8 (Sigma 7)	Oct. 3, 1962 Kearsarge (P)	Navy Comdr. Walter M. Schirra, Jr.	9:13:11	6 orbits
Mercury Atlas 9 (Faith 7)	May 15-16, 1963 Kearsarge (P)	USAF Maj. L. Gordon Cooper	34:19:49	22 orbits
GEMINI				
Gemini 3 (Molly Brown)	March 23, 1965 Intrepid (A)	USAF Maj. Virgil I. Grissom Navy Lt. Comdr. John W. Young	4:53	3 orbits
Gemini 4	June 3-7, 1965 Wasp (A)	USAF Majors James A. McDivitt and Edward H. White, II	97:56	62 orbits; first U.S. EVA (White)
Gemini 5	Aug. 21-29, 1965 Lake Champlain (A)	USAF Lt. Col. L. Gordon Cooper Navy Lt. Comdr. Charles Conrad, Jr.	190:55	120 orbits
Gemini 7	Dec. 4-18, 1965 Wasp (A)	USAF Lt. Col. Frank Borman Navy Comdr. James A. Lovell, Jr.	330:35	Longest Gemini flight; rendezvous target for Gemini 6; 206 orbits
Gemini 6	Dec. 15-16, 1965 Wasp (A)	Navy Capt. Walter M. Schirra, Jr. USAF Maj. Thomas P. Stafford	25:51	Rendezvoused within 1 ft. of Gemini 7; 16 orbits
Gemini 8	Mar. 16, 1966 L. F. Mason (P)	Civilian Neil A. Armstrong USAF Maj. David R. Scott	10:41	Docked with unmanned Agena 8; 7 orbits
Gemini 9A	June 3-6, 1966 Wasp (A)	USAF Lt. Col. Thomas P. Stafford Navy Lt. Comdr. Eugene A. Cernan	72:21	Rendezvous (3) with Agena 9; one EVA; 44 orbits
Gemini 10	July 18-21, 1966 Guadalcanal (A)	Navy Comdr. John W. Young USAF Maj. Michael Collins	70:47	Docked with Agena 10; rendezvoused with Agena 8; two EVAs; 43 orbits

NOTES: 1. Names in parentheses are crew names for spacecraft and Lunar Modules. 3. Hours and minutes, except for Skylab.
2. (A) or (P) denotes Atlantic or Pacific Ocean splashdown. 4. EVA refers to extravehicular activity, or activity outside the spacecraft; LM refers to Lunar Module.

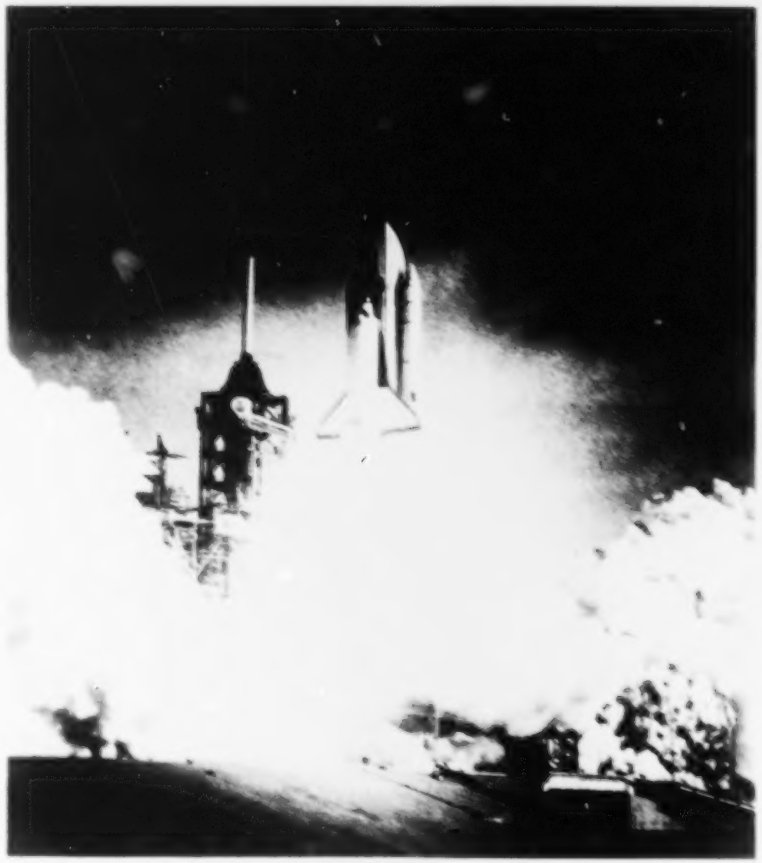
Gemini 11	Sept. 12-15, 1966 Guam (A)	Navy Comdr. Charles Conrad, Jr. Navy Lt. Comdr. Richard F. Gordon, Jr.	71:17	Docked with Agena 11 twice; first tethered flights; two EVAs; highest altitude in Gemini program; 853 miles; 44 orbits
Gemini 12	Nov. 11-15, 1966 Wasp (A)	Navy Capt. James A. Lovell, Jr. USAF Maj. Edwin E. Aldrin, Jr.	94:35	Three EVAs total 5 hrs. 30 min.; 59 orbits
APOLLO				
Apollo 1	Jan. 27, 1967	USAF Lt. Col. Virgil I. Grissom USAF Lt. Col. Edward H. White, II Navy Lt. Comdr. Roger Chafee		Planned as first manned Apollo Mission; fire during ground test on 1/27/67 took lives of astronauts; posthumously designated as Apollo 1.[5]
Apollo 4	Nov. 4, 1967 Bennington (P)	Unmanned	9:37	First flight of Saturn V launch vehicle. Placed unmanned Apollo command and service module in Earth orbit.
Apollo 5	Jan. 22, 1968	Unmanned	7:50	Earth orbital flight test of unmanned Lunar Module. Not recovered
Apollo 6	April 4, 1968 Okinawa (P)	Unmanned	9:57	Second unmanned test of Saturn V and Apollo
Apollo 7	Oct. 11-22, 1968 Essex (A)	Navy Capt. Walter M. Schirra, Jr. USAF Maj. Donn Eisele Civilian Walter Cunningham	260:08:45	Tested Apollo Command Module in Earth orbit; 163 orbits
Apollo 8	Dec. 21-27, 1968 Yorktown (P)	USAF Col. Frank Borman Navy Capt. James A. Lovell, Jr. USAF Lt. Col. William Anders	147:00:11	First manned Saturn V launch; 10 lunar orbits
Apollo 9 (Gumdrop and Spider)	March 3-13, 1969 Guadalcanal (A)	USAF Col. James A. McDivitt USAF Col. David R. Scott Civilian Russell L. Schweickart	241:00:53	Earth orbital mission; first manned flight of LM; two EVAs total 2 hrs. 8 min.; 151 orbits
Apollo 10 (Charlie Brown and Snoopy)	May 18-26, 1969 Princeton (P)	USAF Col. Thomas P. Stafford Navy Comdr. John W. Young Navy Comdr. Eugene E. Cernan	192:03:23	31 lunar orbits; LM descended to within nine miles of lunar surface
Apollo 11 (Columbia, Eagle)	July 16-24, 1969 Hornet (P)	Civilian Neil Armstrong USAF Lt. Col. Michael Collins USAF Col. Edwin E. Aldrin, Jr.	195:18:35	First manned lunar landing; Sea of Tranquility; one lunar EVA 2 hrs. 48 min.; 46 lbs. lunar samples
Apollo 12 (Yankee Clipper and Intrepid)	Nov. 14-24, 1969 Hornet (P)	Navy Comdr. Charles Conrad, Jr. Navy Comdr. Richard F. Gordon, Jr. Navy Comdr. Alan L. Bean	244:36:25	Landed Ocean of Storms; two lunar EVAs total 7 hrs. 46 min. 75 lbs. samples

NOTES: 5. There were no missions designated as Apollo 2 and Apollo 3

Apollo 13 (Odyssey and Aquarius)	April 11-17, 1970 Iwo Jima (P)	Navy Capt. James A. Lovell, Jr. Civilian Fred W. Haise, Jr. Civilian John L. Swigert, Jr.	142:54:41	Lunar landing aborted after oxygen tank ruptured; safe recovery
Apollo 14 (Kitty Hawk and Antares)	Jan. 31-Feb 9, 1971 New Orleans (P)	Navy Capt. Alan B. Shepard, Jr. USAF Maj. Stuart A. Roosa Navy Comdr. Edgar D. Mitchell	216:02:01	Landed Fra Mauro; two lunar EVAs total 9 hrs. 23 min.; 94 lbs. samples
Apollo 15 (Endeavour and Falcon)	July 26-Aug. 7, 1971 Okinawa (P)	USAF Col. David R. Scott USAF Lt. Col. James B. Irwin USAF Maj. Alfred M. Worden	295:12:00	Landed Hadley Apennine; three lunar EVAs total 18 hrs. 46 min.; 169 lbs. samples
Apollo 16 (Casper and Orion)	April 16-27, 1972 Ticonderoga (P)	Navy Capt. John W. Young Navy Lt. Comdr. Thomas K. Mattingly, II USAF Lt. Col. Charles M. Duke, Jr.	265:51:06	Landed Descartes highlands; three lunar EVAs total 20 hrs. 14 min., 213 lbs. samples
Apollo 17 (America and Challenger)	Dec. 7-19, 1972 Ticonderoga (P)	Navy Capt. Eugene A. Cernan Navy Comdr. Ronald E. Evans Civilian Harrison H. Schmitt (Ph. D.)	301:51:59	Landed Taurus-Littrow; three lunar EVAs total 22 hrs. 4 min.; 243 lbs. samples
SKYLAB				
Skylab 1	Launched May 14, 1973	Unmanned	Re-entered atmosphere 7-11-79 on orbit 34,981	100-ton space station visited by three crews
Skylab 2	May 25-June 22, 1973 Ticonderoga (P)	Navy Capt. Charles Conrad, Jr. Navy Comdr. Paul J. Weitz Navy Comdr. Joseph P. Kerwin (M. D.)	28 days 49 min. 49 sec.	Repaired Skylab; 404 orbits; 392 experiment hours; three EVAs total 5 hrs. 34 min.
Skylab 3	July 28-Sept. 25, 1973 New Orleans (P)	Navy Capt. Alan L. Bean Marine Maj. Jack R. Lousma Civilian Owen K. Garriott (Ph. D.)	59 days 11 hrs. 9 min. 4 sec.	Performance maintenance, 858 orbits; 1,081 experiment hours; three EVAs total 13 hrs. 42 min.
Skylab 4	Nov. 16, 1973- Feb. 8, 1974 New Orleans (P)	Marine Lt. Col. Gerald P. Carr USAF Lt. Col. William R. Pogue Civilian Edward G. Gibson (Ph. D.)	84 days 1 hr. 15 min. 31 sec.	Observed Comet Kohoutek; 1,214 orbits; 1,563 experiment hours; four EVAs total 22 hrs. 25 min.
ASTP				
Apollo Soyuz Test Project	July 15, 1975- July 24, 1975 New Orleans (P)	USAF Brig. Gen. Thomas P. Stafford Civilian Vance D. Brand Civilian Donald K. Slayton	9 days 1 hr. 28 min. 24 sec.	Apollo docked with Soviet Soyuz spacecraft[6] July 17; separated July 19

NOTES: 6. Flown by Cosmonauts Aleskey A. Leonov and Valeriy N. Kubasov; mission duration 5 days, 22 hours, 30 minutes, 54 sec.

THE FUTURE OF MANNED SPACE FLIGHT



First (STS-1) liftoff of the Space Shuttle, April 12, 1981.

The 2-million kilogram (4.5 million pound) Space Shuttle is the first vehicle designed to carry both crew and large unmanned applications and scientific spacecraft into orbit. The primary function of prior manned missions was the scientific exploration of the space environment, or the surface of the Moon. Large spacecraft, such as the many geosynchronous orbit communications and weather satellites, planetary explorers, or scientific research probes, were launched on unmanned vehicles. The Space Shuttle combines the weightlifting capacity of the largest unmanned launchers with the unmatched ability of an on the spot human being to make decisions and take actions.

No machine yet built can equal a trained astronaut at problem solving in space, as the recovery and eventual success of the Skylab program amply demonstrated. Shuttle astronauts have repaired satellites in space and recovered others for more extensive repairs on the ground.

The Space Shuttle has flown with one crew of eight men and women, and seven crewmembers has been a common number. It has combined thrust at liftoff of about 28.6 million newtons (6.5 million pounds) from its two solid rocket boosters and the three liquid propellant main engines on the orbiter. Its top capacity into low Earth orbit will be 29,500 kilograms (65,000 pounds) in its fully operational configuration. This can consist of one large payload, a combination of up to three spacecraft with attached solid stages for injection into higher orbits, along with smaller packages that remain with the orbiter but must operate in the space environment, or a mixture of these types of payloads. The Space Shuttle is the only American vehicle designed for both manned spaceflight and delivering heavy payloads into Earth orbit that is expected to be available for the rest of this century.

NASA

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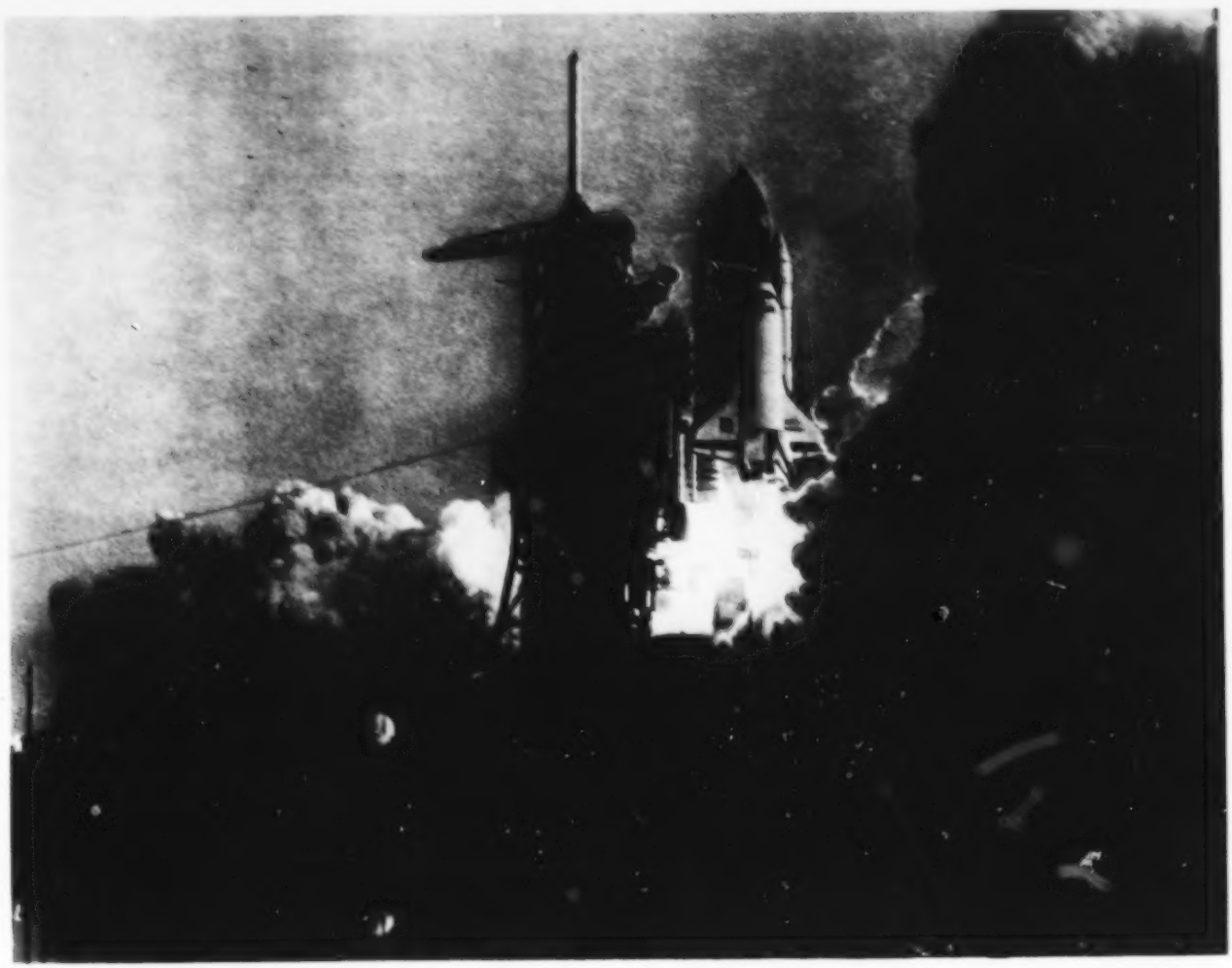
National Aeronautics and
Space Administration

Information Summaries

PMS 003-A (KSC)
January 1988

Space Shuttle Mission Summary 1981-1983

STS Missions 1 thru 9



Space Shuttle Missions in Brief 1981-1983

MISSION NAME	ASTRONAUTS	LAUNCH DATE	ORBITER	PRIMARY PAYLOAD	LAUNCH PAD	RESULT
STS-1	Young, Crippen	4/12/81	Columbia	—	39A	S
STS-2	Engle, Truly	11/12/81	Columbia	OSTA-1	39A	S
STS-3	Lousma, Fullerton	3/22/82	Columbia	OSS-1	39A	S
STS-4	Mattingly, Hartsfield	6/27/82	Columbia	DoD 82-1	39A	S
STS-5	Brand, Overmeyer, Lenoir, Allen	11/11/82	Columbia	SBS-C/ Anik C-3	39A	S
STS-6	Weitz, Bobko, Musgrave, Peterson	4/4/83	Challenger	TDRS-A	39A	S
STS-7	Crippen, Hauck, Ride, Fabian, Thagard	6/18/83	Challenger	Anik C-2/ Palapa B-1/ SPAS-01/OSTA-2	39A	S
STS-8	Truly, Brandenstein, Bluford, Gardner, Thornton	8/30/83	Challenger	INSAT 1B	39A	S
STS-9	Young, Shaw, Parker, Garriott, Merbold, Lichtenberg	11/28/83	Columbia	Spacelab 1	39A	S

This summary provides the most pertinent and important details of all Space Transportation System (STS) missions through the end of 1983, including a brief description of the payloads and experiments performed in orbit. All nine missions required that the Space Shuttle orbiter be returned to the Kennedy Space Center by the 747 carrier aircraft after landing. The first four missions formed the Orbital Flight Test Program; all subsequent missions were operational. This summary is not intended to be comprehensive or complete, and covers only the first three years of Space Shuttle flights. A new summary will be issued at the end of each calendar year, covering only those launches that occurred during the previous 12 months.

STS-1 Mission

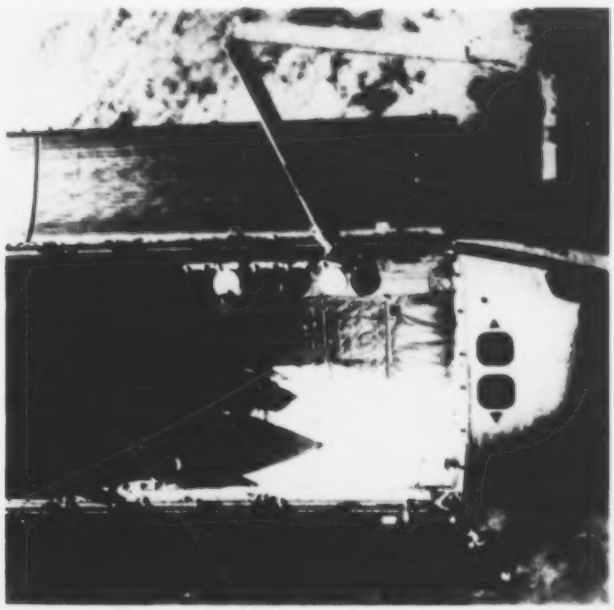
The Orbiter Columbia lifted off from Pad A, Launch Complex 39, Kennedy Space Center, (KSC) Florida, at 7:00 a.m. EST on April 12, 1981, after a launch attempt on April 10 was scrubbed due to a timing skew in the orbiter general purpose computer system. Columbia had remained in the Orbiter Processing Facility for 610 days after its arrival at KSC, due primarily to the replacement of the lightweight protective tile installed at the factory. This launch marked the first use of solid rockets on a manned vehicle, and the first time astronauts rode a new type of spaceship on its first flight. The primary mission objectives were a safe ascent into orbit, then a return to Earth for a landing on the orbiter's own wheels. Columbia landed on Runway 23, Edwards Air Force Base (AFB), California, on April 14, 1981, at 1:21 p.m. EST, after a mission duration of two days, six hours, and 21 minutes. It had completed 36 orbits. Post-flight investigation revealed that Columbia had suffered some damage from an overpressure wave created by the solid rocket boosters at ignition, had lost 16 tiles, and had damaged 148. Columbia was otherwise in good condition.

Astronaut Robert Crippen floats in the weightlessness of microgravity inside the middeck area of Columbia on STS-1.

Crew. The crew members were John W. Young, Commander, and Robert L. Crippen, Pilot.

Payload and Experiments. Columbia carried the Development Flight Instrumentation (DFI) package, which contained strain sensors and measuring devices to report on spacecraft performance and the stresses encountered during launch, flight, and landing, but otherwise had no cargo.

STS-2 Mission



This view of the Orbiter Challenger above a mountainous region of the Earth, taken by the SPAS-01 platform floating above it during STS-7, shows the Remote Manipulator System "Canadarm" at the upper right center, extended up and back toward the crew compartment. The cylinders attached along the cargo bay walls are "Getaway Special" canisters.

Crew. The crew members were Joseph H. Engle, Commander, and Richard H. Truly, Pilot.

Payload and Experiments. Columbia again carried the DFI package of special sensors to report on the performance of the spacecraft and its various systems. The Canadian-built Remote Manipulator System arm (Canadarm) was operated by the crew in all its modes. The only payload was OSTA-1 (after the NASA "Office of Space and Terrestrial Applications"), a set of instruments mounted on a Spacelab pallet in the cargo bay. The experiments performed were in the areas of remote sensing of land resources, environmental quality, ocean conditions, and meteorological phenomena. One instrument, the Shuttle Imaging Radar-A (SIR-A), performed the unexpected feat of "looking through" several feet of dry sand in a desert region of North Africa to outline the original land surface, including dried riverbeds and rocky hills.

STS-3 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00 a.m. EST on March 22, 1982. The launch had been delayed one hour by the failure of a heater on a nitrogen gas ground support line. Liftoff did occur on the originally scheduled day. Columbia's time in the Orbiter Processing Facility decreased to 70 days. The major mission goals were to perform further tests of the Canadarm and extensive thermal testing of the Columbia itself. The latter was accomplished by exposing the tail, nose and top to the Sun for varying periods of time, rolling it in between tests to stabilize temperatures over the entire body. The Canadarm tested satisfactorily, moving the Plasma Diagnostics Package experiment around the orbiter.

The planned seven-day mission was extended one day due to high winds at the back-up landing site, the Northrup Strip at White Sands, New Mexico. (The Edwards AFB primary landing site was too wet for a safe landing.) Columbia landed at Northrup Strip, March 30, 1982, at 11:05 a.m. EST, after a mission duration of eight days and five minutes. It had completed 129 orbits. A total of 36 tiles were lost and 19 damaged.

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 10:10 a.m. EST on November 12, 1981. The launch was delayed from a planned 7:30 a.m. liftoff by the need to replace one of Columbia's on-board data transmitting units. It had previously been delayed from a planned November 4 launch because of an apparent low reading on fuel cell oxygen tank pressure, followed by the changing of oil filters in two of the three auxiliary power units. This time Columbia went through the Orbiter Processing Facility in 103 days. Modifications to the water sound suppression system to absorb the overpressure wave from the solid rocket boosters were successful. This was the first time a launched spaceship was reflown with a second crew. During the flight a problem developed with one of the three fuel cells, and the mission duration was shortened from its planned five days. The crew nevertheless achieved 90% of the mission objectives. Columbia landed on Runway 23, Edwards AFB, on November 14, 1981, at 4:23 p.m. EST, after a mission duration of two days, six hours, and 13 minutes. It had completed 36 orbits. Tile damage was minor.

Astronaut Gordon Fullerton performs some intricate calculations using a hand-held calculator during the STS-3 mission.

Crew. The crew members were Jack R. Lousma, Commander, and C. Gordon Fullerton, Pilot.

Payload and Experiments. In its cargo bay Columbia carried a "Getaway Special" test canister and a Spacelab pallet-mounted set of experiments for NASA's Office of Space Science and Applications called OSS-1. The latter obtained data on the near-Earth space environment, including the degree of contamination (gases, dust, outgassing particles) introduced by the orbiter itself. In the cabin middeck area were experiments on lignin formation in weightlessness, insect motion (the latter was the first Shuttle Student Involvement Project, or SSIP, to fly), a Continuous Flow Electrophoresis system to investigate separation of biological components, and a Monodisperse Latex Reactor experiment to produce micron-sized latex particles of uniform diameter. Columbia also flew the DFI package for the third time, and instruments to study catalytic surface effects, tile gap heating effects, and the dynamic, acoustic, and thermal environment around the orbiter.

STS-4 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00 a.m. EDT on June 27, 1982. This was the first Space Shuttle to be launched on time and with no delays in schedule. Orbiter time in the Processing Facility was reduced to 42 days. The mission goals were to further test the flying, handling, and operating characteristics of the orbiter, to perform more exercises with the Canadarm, to conduct several scientific experiments in orbit, and to land at Edwards AFB for the first time on a concrete runway, one the same length as the Shuttle Landing Facility at KSC. Columbia was also scheduled for more thermal tests by exposure to the Sun in selected attitudes, but these plans were changed. Some hail that fell while Columbia was on the pad cut through the protective coating on the tiles and let some rainwater penetrate inside. In space the affected area on the underside was turned to the Sun, which vaporized the water and prevented further possible tile damage from freezing.

The only major problem on this mission was the loss of the two solid rocket booster casings. The main parachutes failed to function properly and the two casings hit the water at too high a velocity and sank. They were later found and examined by remote camera, but not recovered. Columbia landed on Runway 22, Edwards AFB, on July 4, 1982, at 12:09 p.m. EDT, after a mission duration of seven days, one hour and ten minutes. It had completed 112 orbits. President and Mrs. Reagan attended the landing and welcoming ceremonies.

Crew. The crew members were Thomas K. Mattingly, Commander, and Henry W. Hartsfield, Pilot.

Payload and Experiments. In addition to a classified Air Force payload in the cargo bay, STS-4 carried the first Getaway Special – a series of nine experiments prepared by students from Utah State University. In the middeck area the astronauts operated a second and larger Continuous Flow Electrophoresis System and a second Monodisperse Latex Reactor experiment. They also performed a cloud-top lightning survey using hand-held cameras, and took medical data on themselves for two student experiments. They operated the Canadarm again to move an instrument called the Induced Environmental Contamination Monitor around the orbiter in space, to gather data on any gases or particles being released by the orbiter.

STS-5 Mission

The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 7:19 a.m. EST on November 11, 1982. This was the second Space Shuttle to be launched on time and with no delays in schedule. It was the first operational flight for the STS, with two commercial communications satellites, a number of experiments, and a four-astronaut crew. The latter became the "We Deliver" team when they successfully launched both satellites, ready for their trips into higher orbits. The only real problems during the mission occurred with the two spacesuits. The two Mission Specialist astronauts were scheduled to perform an extravehicular activity, but this had to be cancelled due to the malfunction of a ventilation motor in one suit and a pressure regulator in the other. Columbia landed on Runway 22, Edwards AFB, on November 16, 1982, at 9:33 a.m. EST, after a mission duration of five days, two hours and 14 minutes. It had completed 81 orbits.

Crew. The crew members were Vance Brand, Commander, Robert F. Overmyer, Pilot, and Dr. Joseph P. Allen and Dr. William B. Lenoir, Mission Specialists.

Payload and Experiments. Two very similar communications satellites, SBS-3 and Anik C-3, built by Hughes Aircraft as part of the company's HS-376 series, were deployed for Satellite Business Systems and Telesat of Canada, respectively. Each was equipped with a Propulsion Assist Module (PAM) solid rocket motor, which fired automatically about 45 minutes after deployment and placed each satellite in a highly elliptical orbit. The company controllers of each later fired an on-board solid motor at apogee, and circularized the orbits. Both satellites were then checked out by their owners and entered into commercial service. Three SSIP experiments were conducted for student experimenters by the astronauts working in the middeck area, as was a third Monodisperse Latex Reactor test. The first of 25 Getaway Special experiments reserved by West Germany was conducted in the cargo bay, where X-rays of a molten mixture of mercury and gallium were taken to observe the effects of microgravity on the dispersion of mercury droplets into the gallium. A group of instruments provided additional information about Shuttle aerodynamics, atmospheric entry heating rates on different sections, the cargo bay environment, and other Shuttle properties.

STS-6 Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 1:30 p.m. EST on April 4, 1983. This was the first launch of the second Space Shuttle orbiter, which

was considered an operational vehicle on its initial flight. The originally scheduled launch date of January 20 was postponed twice, once for a hydrogen gas leak that required removal, repair and reinstallation of two of the Space Shuttle Main Engines and replacement of the third, and once because of payload contamination caused by a severe storm at the pad. The hydrogen leak was detected as a result of a 20-second Flight Readiness Firing of the main engines on December 18, 1982. This led to a second firing on January 25, 1983, which confirmed the leakage. As engine repairs were being performed a severe storm with high winds breached the seals between the Payload Changeout Room in the Rotating Service Structure and their contact with the orbiter around the cargo bay. Particulate matter was blown inside. The payload had to be removed and returned to a checkout facility to be cleaned, and the Changeout Room and cargo bay were cleaned while it was away. On the new launch date Challenger lifted off on time, with no further problems. Its satellite payload was released into low Earth orbit as planned. The two Mission Specialists completed planned spacewalks using the new spacesuits. Challenger landed on Runway 22, Edwards AFB, on April 9, 1983, at 1:53 p.m. EST, after a mission duration of five days and 25 minutes. It had completed 80 orbits.

Crew. The crew members were Paul J. Weitz, Commander, Karol J. Bobko, Pilot, and Donald H. Peterson and Dr. Story Musgrave, Mission Specialists.

Payload and Experiments. The primary payload for STS-6 was the first Tracking and Data Relay (TDRS) satellite. It weighed about 5,000 pounds, and was to be injected into a geosynchronous transfer orbit by a 32,000-lb, two-stage, solid propellant Inertial Upper Stage (IUS). The first stage fired as planned, but when the second stage fired at apogee, it cut off after 70 seconds of a planned 103-second burn. TDRS entered an unsatisfactory elliptical orbit. More propellant had been loaded aboard than was needed for its planned operational life, and this was used over the next several months to gradually circularize the orbit, using the spacecraft's own attitude control thrusters. The maneuver was successful, and TDRS-1 reached geosynchronous orbit and entered normal service. TDRS-1 was the first of three planned satellites to serve as orbiting relay and control stations for other spacecraft, making it possible to eliminate most of the system of ground tracking stations used prior to the Shuttle era. A TDRS can handle up to 300 million bits of information each second from a single user spacecraft. It operates in both Ku-band and S-band frequencies. The system of three satellites will be able to provide coverage for low-Earth orbit satellites (including the Space Shuttle) almost 100 percent of the time, compared to the 15-percent coverage now common for most such spacecraft.

STS-6 also had three Getaway Specials in the cargo bay, one each on artificial snow formation, a packaged seed collection, and a composite metals experiment.

The first test of the new type of space suit designed for Shuttle astronauts was also completed with astronauts Musgrave and Peterson performing various tests in the cargo bay during four hours and 17 minutes of extravehicular activity. These tests went well. The Monodisperse Latex Reactor and Continuous Flow Electrophoresis experiments were also flown again and operated successfully.

The Palapa-B geosynchronous communications satellite has just popped out of the open sunshield below as it climbs into space at a rate of three feet per second, while spinning at 50 rpm.

STS-7 Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 7:33 a.m. EDT on June 18, 1983. The launch was on time and with no delays in schedule. This was the third operational flight of the Space Shuttle, and the second with a payload of two commercial communications satellites. It also featured a large variety of other items of cargo. This was the first STS launch with a crew of five astronauts, and the first flight of an American woman into space. The crew successfully deployed the two satellites, on the first and second days of the mission, and performed a series of other experiments. The Shuttle Ku-band antenna used with the TDRS satellite was successfully tested. The experiments among the seven Getaway Special canisters in the cargo bay that required start-and-stop operations were performed by the astronauts.

The Shuttle Pallet Satellite (SPAS-01) mounted in the cargo bay, which was built and supplied by the West German firm Messerschmitt-Bolkow-Blohm, was released into space by the Canadarm. Operating under its own power, it flew alongside Challenger for several hours, during which time a United States-supplied camera photographed Challenger against a background of Earth. The SPAS-01 was grappled twice by the Canadarm, then returned and locked into position in the cargo bay. Challenger was maneuvered away from and toward the SPAS-01 during these activities.

A second set of experiments called OSTA-2, supplied by the United States and the Federal Republic of Germany, was mounted on a special support structure in the cargo bay.

Astronaut Norman Thagard, a mission specialist and medical doctor, conducted medical tests in orbit on the problem of Space Adaptation Syndrome, the condition that

often leads to nausea and sickness during the early hours of flight.

Astronaut Sally Ride uses a screwdriver to release and clean an air filter during the STS-7 mission. Dr. Ride was the first American woman to go into space. The acronym on her T-shirt means "Thirty-five New Guys" for the group who trained with her to become astronauts.

STS-7 was scheduled to land at the Shuttle Landing Facility at KSC, but rainy weather forced a landing at Edwards AFB. Challenger landed on Runway 23 on June 24, 1983, at 9:57 a.m. EDT, after a mission duration of six days, two hours and 24 minutes. It had completed 97 orbits.

Crew. The crew members were Robert L. Crippen, Commander, Frederick C. Hauck, Pilot, and John M. Fabian, Dr. Sally K. Ride and Dr. Norman Thagard, Mission Specialists.

Payload and Experiments. The primary payload was two satellites built by Hughes Aircraft in its HS-376 series – Telesat's Anik C-2 (launched out of sequence behind Anik C-3 on STS-5) and Indonesia's Palapa B. The latter is the first of a second generation of communications satellites for PERUMTEL, the state-owned telecommunications company supplying modern communications to bind together the 3,000 islands of Indonesia. Both spacecraft were attached to PAM motors, which fired on schedule and successfully placed both into geosynchronous transfer orbits. Later, the on-board apogee motor of each was fired to circularize the orbit. Both entered service under the control of their owners.

Several Getaway Special canisters in the cargo bay held a wide variety of experiments, including ones on the effects of space on the social behavior of an ant colony in zero gravity, soldering operations, germination of radish seeds, and others. Ten experiments mounted on the SPAS-01 pallet performed research in the areas of forming metal alloys in microgravity, operating heat pipes, using a remote sensing scanner, utilizing a mass spectrometer to identify gases in the cargo bay, verifying a means of calibrating solar cells, and more.

Challenger's small control rockets were fired while SPAS-01 was held by the Canadarm, to test the effects of movement on the extended arm. The Monodisperse Latex Reactor and Continuous Flow Electrophoresis experiments in the middeck area were operated by the astronauts as required. Astronaut Thagard measured fluid motion and pressure increase inside the head and checked eye movement and visual perception, both in himself and the other astronauts, gathering data on the effects of Space Adaptation Syndrome. A set of OSTA-2 experiments in the cargo bay were operated for materials processing experiments as planned.

STS-8 Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 2:32 a.m. EDT on August 30, 1983. This was the first night launch of a Space Shuttle. The time of launch was dictated by the tracking requirements for the primary payload, the INSAT 1B satellite being launched for India. It was the first spaceflight by an American black astronaut. It was the second launch where a Mission Specialist medical doctor conducted tests on himself and the other crew members to gather data on the cause of Space Adaptation Syndrome sickness. Ground operators performed some 20 tests of the TDRS satellite using the orbiter's S-band and Ku-band antenna systems, most without astronaut assistance. The relaying capabilities of the TDRS were being tested in preparation for the high data rate necessary to support the upcoming first Spacelab mission.

Astronaut Guion Bluford, the first American black astronaut to perform a spaceflight, runs on a treadmill while wired to monitors that recorded the results of his exercise.

The INSAT 1B was deployed on the second day. The Challenger's nose was held away from the Sun for 14 hours, to test the flight deck area in the extreme cold. The crew at this time filmed the performance of an experimental heat pipe mounted in the cargo bay. On the fourth day the Challenger dropped down to 139 miles altitude to perform a series of tests on the thin atomic oxygen there, as part of an effort to identify the cause of the "glow" that tends to surround parts of the orbiter at night. The Canadarm was exercised using a special 7,460 pound weight designed for that purpose. Due to the fact it was to be the first night landing, Challenger was brought down at Edwards AFB, landing on September 5, 1983, at 3:41 a.m. EDT, after a

mission duration of six days, one hour and nine minutes. It had completed 96 orbits.

Crew. The crew members were Richard H. Truly, Commander, Daniel C. Brandenstein, Pilot, and Dale A. Gardner, Guion S. Bluford and William E. Thornton, Mission Specialists.

Payload and Experiments. The primary payload was the INSAT 1B spacecraft, a multipurpose satellite for India that can provide telecommunications, relay television signals to small home and community antennas in rural areas, and provide high-resolution infrared and visible light photographs of the complete Earth disk every 30 minutes for meteorological analysis and storm warnings. Formerly, a separate satellite was required for each of these major functions. The attached PAM-D stage fired automatically 45 minutes after deployment, placing the satellite in a geosynchronous transfer orbit. Two days later the on-board apogee motor was fired to circularize the orbit, after which the owner/controllers began checkout procedures.

Also in the cargo bay were 12 Getaway Special canisters, four containing experiments and eight holding STS-8 postal covers (plus more in two boxes mounted on an instrument panel, for a total of 260,000) for sale to the public after the flight.* The Continuous Flow Electrophoresis System experiment was flown again, this time using live cells. An SSIP experiment in bio-feedback training was conducted on the astronauts. Six live rats were flown on the mission, in a new animal enclosure module being flight-tested for the first time. Dr. Thornton performed a series of biomedical experiments on himself and the other crew members, continuing the work began by Dr. Thagard on STS-7 on Space Adaptation Syndrome sickness.

Space Shuttle Challenger climbs into the darkened sky to begin the STS-8 mission, the only night launch of the Space Shuttle during the first three years. It also landed at night.

**Persons interested in obtaining these covers should write to: Shuttle Flight Folders Philatelic Sales Division, Washington, D.C. 20265-9997.*

STS-9 Mission

STS-9 Mission (STS 41-A Mission). The Orbiter Columbia lifted off from Pad A, Launch Complex 39, KSC, at 11:00 a.m. EST on November 28, 1983. This was the first time six persons were launched into space on a single vehicle. The primary payload was Spacelab 1, a joint ESA/NASA venture that forms the major scientific investigation project associated with the Space Shuttle. A Spacelab rides in the cargo bay of an orbiter, and never flys free. This mission included two astronauts of a new type, Payload Specialists who had trained specifically to perform experiments in the Spacelab and were not NASA employees or career astronauts. Although some instruments were carried in the middeck area they were also part of Spacelab 1; this mission was entirely devoted to Spacelab.

STS-9 verified the ability of Principal Investigators at the Payload Operations Control Center (recently installed at Johnson Space Center) to interact with astronauts in orbit on a "live" basis, greatly enhancing experimentation. This was also the first actual use of the high-capacity TDRS satellite to relay to its ground station a very large volume of data. The Spacelab experiments produced far more data than earlier payloads.

The six-man crew was divided into two teams for 24-hour continuous work. Young, Parker and Merbold (the latter the first European to fly on a Space Shuttle) formed the red team and Shaw, Garriott and Lichtenberg (the latter the first non-NASA American astronaut to fly in space) formed the blue team. The commander and pilot team members were usually stationed on the flight deck, while the Mission Specialist and Payload Specialist operated from inside the Spacelab. The work went so well the mission was extended from nine to ten days, becoming the longest STS mission to date.

Columbia landed at Edwards AFB on December 8, 1983, at 6:47 p.m. EST, after a delay of 7.5 hours caused by a malfunction of two of the Orbiter's general purpose computers and one inertial measurement unit. Several small fires were discovered in the tail section after landing, caused by leaks of hydrazine from the Auxiliary Power Units into the compartment. The mission duration was 10 days, seven hours and 47 minutes. Columbia had completed 166 orbits, the largest number in STS history to date.

Crew. The crew members were John W. Young, Commander, Brewster H. Shaw, Pilot, Owen Garriott and Robert Parker, Mission Specialists, and Ulf Merbold of West Germany and Bryon Lichtenberg of the Massachusetts Institute of Technology, Payload Specialists.

Payload and Experiments. Spacelab is an orbital laboratory and observation platform composed of cylindrical pressurized modules and U-shaped unpressurized pallets. The Spacelab remains physically inside the orbiter cargo bay, but is exposed to space when the cargo bay doors are open. The Spacelab elements can be arranged in various combinations and are reusable, most designed to be refurbished and relaunched as many as 50 times, over a lifespan of ten years.

The first Spacelab was funded by the European Space Agency, as a major contribution to the STS Program. A second set of Spacelab components was purchased by NASA. Spacelab 1 utilized one each core and experiment modules (combined and pressurized) and one pallet. The core module contained a window/viewport and the experiment module a cylindrical scientific airlock, the latter some three feet three inches in both length and diameter.

Most Spacelab missions are expected to be devoted to a single scientific discipline (e.g. astronomy, Earth resources, materials processing, etc.), but Spacelab 1 was a proof-of-concept flight and performed experiments in several areas. These included atmospheric and plasma physics, astronomy, solar physics, material sciences, technology, life sciences and Earth observations. The experiment payload was divided roughly in half by weight between ESA and NASA. The astronauts performed numerous experiments in all areas. A very large amount of data was accumulated, which is still being analyzed. The essential assumptions of the Spacelab operating program were all proven in practice. These were: using non-NASA astronauts trained only as Payload Specialists; a scientific command center on the ground to provide close collaboration with the astronauts in orbit; the ability of TDRS to relay the data; and the ability of Spacelab to support complex experiments in all planned scientific areas.

Mission Specialist Dr. Robert Parker hovers in space, wired for biomedical experiments with sensors attached to his torso. Dr. Ulf Merbold's body can be seen at the upper right.

NASA
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Information Summaries

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January 1988

Space Shuttle Mission Summary

1984

STS Missions 41-B thru 51-A

Astronaut Dale A. Gardner flies his Manned Maneuvering Unit toward the spinning Westar VI satellite on the STS 51-A mission, holding a capture device called a "stinger" in front of him. Westar VI became one of the first two satellites to be recovered in space and returned to Earth for refurbishment and relaunching.

Space Shuttle Missions in Brief 1984

MISSION NAME	ASTRONAUTS	LAUNCH DATE	ORBITER	PRIMARY PAYLOAD	LAUNCH PAD	RESULT
STS 41-B	Brand, Gibson, McCandless, McNair, Stewart	2/3/84	Challenger	Westar VI/ Palapa B-2/ SPAS-01A	39A	S
STS 41-C	Crippen, Scobee, van Hoften, Nelson, Hart	4/6/84	Challenger	Long Duration Exposure Facility	39A	S
STS 41-D	Hartsfield, Coats, Hawley, Resnik, Mullane, Walker	8/30/84	Discovery	SBS-D/ Telstar 3-C/ SYNCOM IV-2	39A	S
STS 41-G	Crippen, McBride, Sullivan, Ride, Leestma, Garneau, Scully-Power	10/5/84	Challenger	ERBS/OSTA-3	39A	S
STS 51-A	Hauck, Walker, Allen, Fisher, Gardner	11/8/84	Discovery	Anik D-2/ SYNCOM IV-1	39A	S

STS 41-B Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 8:00 a.m. EST on February 3, 1984. This was the first launch of a Space Shuttle under the new numbering system, where the first numeral stands for the year, the second for the launch site (1 for KSC, 2 for Vandenberg), and the letter for the original order of assignment. The primary mission goal was to deploy two commercial communications satellites, but 41-B also featured an ambitious set of experiments. These included the first untethered flights of astronauts using the new Manned Maneuvering Unit (MMU); the second flight of the West German space platform named SPAS, which had flown on STS-7 and so became the first spacecraft to be refurbished and flown on a second mission; the release of an inflated balloon, and two days of orbiter rendezvous maneuvers with the balloon as target; operations with the new Manipulator Foot Restraint that enables astronauts to use the Remote Manipulator System (RMS) Canadarm as a mobile work platform; equipment with which to practice planned repairs on the Solar Maximum Mission satellite (see the 41-C mission); and a number of smaller middeck experiments and "Getaway Special" canisters in the cargo bay.

At 7:17 a.m. EST on February 11, 1984, Commander Vance Brand landed Challenger at the Kennedy Space Center, the first landing there in the Shuttle program, after a mission duration of 7 days, 23 hours and 17 minutes.

Crew. The crew members were Vance D. Brand, Commander; Robert L. Gibson, Pilot; and Bruce McCandless II, Ronald E. McNair, and Robert L. Stewart, Mission Specialists.

Payload and Experiments. This mission had a large number of payload items. The Hughes-built HS-376 communications satellites for Western Union and Indonesia—WESTAR VI and PALAPA B-2—each had a PAM stage attached. WESTAR VI was deployed about eight hours after launch. Its PAM motor fired as programmed 45 minutes later, but malfunctioned and placed the satellite in an orbit much lower than the planned geosynchronous transfer. The deployment of PALAPA B-2 was delayed to Flight Day 4 because of this failure. It too malfunctioned when the PAM stage fired, entering a very similar low orbit. (See STS 51-A for recovery operations.)

The 6.5-ft. rendezvous targeting balloon burst while being pressurized after its release from the cargo bay. It still formed a large enough target that rendezvous operations were successfully performed. These were to test the techniques planned for the next flight, when the Solar Maximum Mission satellite would be recovered and refurbished in orbit.

On the fifth day astronauts McCandless and Stewart performed spacewalks and operated the MMU, becoming the first humans to fly in space without a safety line. The free flights were performed without difficulty, with McCandless going as far as 320 feet from the orbiter. The astronauts also tested the equipment to be used during the recovery, including a foot restraint held at the end of the RMS Canadarm. Together the two provide an astronaut the equivalent of a ride in a "cherry picker," a movable work station. During a second spacewalk on the seventh day McCandless and Stewart practiced Solar Max capture techniques, using the SPAS platform carried in the cargo bay as a substitute spacecraft. The flight plan called for SPAS to be extended on the end of the Canadarm for these practice captures, but it remained in the cargo bay throughout, due to an electrical problem with the Canadarm wrist.

Also among the experiments were five "Getaway Special" canisters in the cargo bay, featuring experiments in

physics, biology, technology, and materials science. All were turned on as programmed by the astronauts. In the pressurized middeck area were six live rats, being studied in an experiment on arthritis; a Cinema 360 camera used by the crew throughout the mission; another in the series of Monodisperse Latex Reactor experiments; another flight of the Continuous Flow Electrophoresis System (CFES); some materials processing experiments; and other small items. The Latex Reactor and CFES equipment operated successfully, and the other experiments were performed as programmed and returned to Earth for later analysis.

On the STS 41-B mission astronaut Bruce McCandless II tests a "cherry picker" work platform, consisting of a mobile foot restraint held and moved by the Remote Manipulator System Canadarm. With his feet firmly anchored and his tools handy on the arms of vest, McCandless can perform useful work anywhere in the cargo bay or within 50 ft of the orbiter.

STS 41-C Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 8:58 a.m. EST on April 6, 1984. This was the fifth flight for Challenger and the first use of a direct ascent trajectory, where the orbiter's main engines carried it all the way to its planned operational altitude of 288 miles. This meant the Orbital Maneuvering System engines only had to be used once, to circularize the orbit.

The mission had two primary goals, the release into orbit of the retrievable Long Duration Exposure Facility (LDEF), a new type of scientific satellite, and the repair in orbit of the Solar Maximum Mission satellite. The latter was the first planned repair of an orbiting spacecraft. Some of the equipment needed for this job had been carried into space and tested on the STS 41-B mission. STS 41-C also carried a Shuttle Student Involvement Project experiment, a comb of live honeybees, in the middeck area. The Cinema 360 camera flew again in the cargo bay, and the large film IMAX camera made its first trip in the crew compartment.

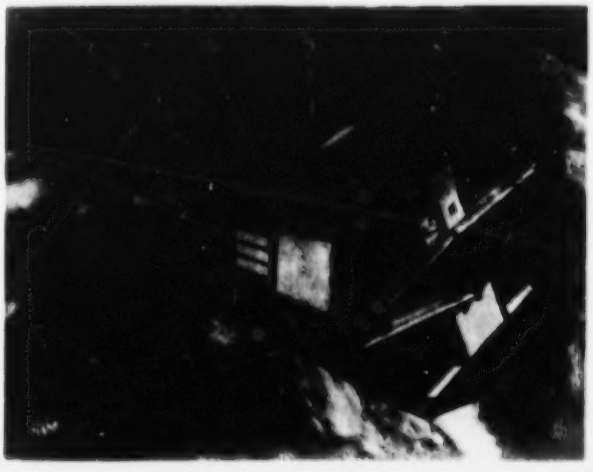
To support the Solar Max rescue effort the Payload Operations Control Center (POCC) at Goddard Space Flight Center had been enlarged and upgraded. The POCC worked closely with the astronaut crew during the repair operations.

STS 41-C was scheduled to land at the Kennedy Space Center, but bad weather in Florida forced a change to Edwards AFB. Challenger landed on Runway 17 on April 13, 1984, at 8:38 a.m. EST, after a mission duration of six days, 23 hours and 40 minutes.

Crew. The crew members were Robert L. Crippen, Commander; Francis R. Scobee, Pilot; and James D. van Hoften, Terry J. Hart and George D. Nelson, Mission Specialists.

Payload and Experiments. The LDEF is a 12-sided cylinder some 14 feet in diameter and 30 feet long. It weighs about 21,300 pounds. The body consists primarily of some 86 removable trays, into which experiments are mounted. There were 57 experiments, contributed by 200 researchers in eight countries, on this first flight; some occupied more than one tray. Each had to be self-contained and automatic in operation after being activated by the release from the orbiter. Most were passive in character, with no moving parts. One, the SEEDS experiment, required exposing some 12 million tomato seeds to the space environment for most of a year.

The LDEF was grappled by the Canadarm and released into orbit on the morning of the second day. It will be recovered during 1985 and the seeds and other experiments returned to their owners. The scientists will determine their individual experiment results. The 12 million tomato seeds will be distributed to approximately one million school children, who will be asked to plant them and some regular seeds and report on the differences in growth rates and mature plants, if any.



The Remote Manipulator System Canadarm suspends the huge Long Duration Exposure Facility high above the Gulf of Mexico prior to releasing it into orbit during the STS 41-C mission. This was the first set of experiments designed to be left in space for a year and then be returned to the Earth for examination and analysis.

The rendezvous with the Solar Max satellite required raising Challenger's orbit to about 300 miles altitude. On the morning of the third day Challenger approached within about 200 feet of Solar Max and "parked" there. Astronauts Nelson and van Hoften donned spacesuits and exited into the cargo bay. Nelson got into the MMU. The capture tool, called the Trunnion Pin Acquisition Device (TPAD), was fixed to the arms of the MMU. Nelson flew out to Solar Max and attempted to clamp the TPAD on a protruding pin, but it failed to lock. After two more efforts that also failed to lock, Nelson was recalled to the orbiter.

The docking attempts had induced tumbling motions in Solar Max, and efforts to grapple it directly with the Canadarm failed because of these. But overnight the POCC at Goddard managed to reestablish control over Solar Max, using its backup system of magnetic torquing bars to stabilize the satellite and place it in a very slow, regular spin. Next morning Challenger, which had moved away before the crew's sleep period, again approached and tried the Canadarm. This time they captured Solar Max on the first try, and brought it into the cargo bay.

Solar Max was locked into a special cradle Challenger had brought for that purpose, and repairs began. Nelson and van Hoften, working in their bulky spacesuits, replaced the spacecraft's faulty Attitude Control Module and a main electronics box for the Coronograph Polarimeter instrument. This required two separate spacewalks, but the work was completed on the second one with time left for van Hoften to perform some engineering tests of the MMU in the cargo bay.

Solar Max was released into orbit next day, checked out for 30 days by the POCC, and began measuring the Sun's total energy output. The savings resulting from repairing this scientific satellite, as opposed to building and launching a new one, amount to many millions of dollars.

The honeybees, after an initial period of disorientation in the weightlessness of space, began building a new honeycomb as expected. The cells were crooked at first, but the bees soon corrected this and the later cells were virtually identical to those built on Earth. The Cinema 360 and IMAX cameras were operated throughout the mission, returning valuable footage. IMAX film from this and later missions will be combined into movies designed for a 50 X 70 foot screen. The huge screen and large film provide extremely fine detail and outstanding clarity.

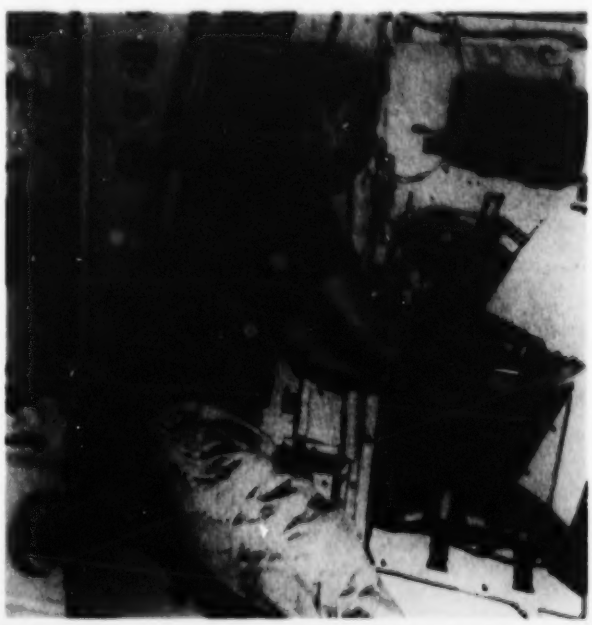
STS 41-D Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 8:41 a.m. EDT on August 30, 1984. The launch was delayed six minutes by an aircraft intruding into the "danger" area over the Atlantic Ocean off the coast. This was the first launch of Discovery, third spaceworthy orbiter in the STS fleet and the lightest one to date. A launch attempt on August 29 failed due to a problem with the computer software for the main engine controllers. Prior to that Discovery had experienced the first abort-after-ignition in the Space Shuttle program, when an earlier launch attempt on June 26, 1984, was scrubbed by the on-board computers four seconds before SRB ignition. Engine No. 3 had lost redundant control over a main fuel valve immediately after ignition. Engine No. 2 had barely ignited, and Engine No. 1 had not, when the shutdown occurred.

Prior to the first launch attempt the main engines of Orbiter Discovery were test-fired on the pad for a 20-second run on June 2, 1984. The performance was nominal, leading to a planned launch date of June 22. This was later changed to June 25. The launch attempt on that date was scrubbed, late in the countdown, due to a failure in the backup General Purpose onboard computer. It was changed out and the substitute computer performed well during the aborted launch attempt next day.

After the launch abort the 41-D mission was remanifested to include the most important payload items from both the originally planned cargo and that intended for 41-F, which was then cancelled. (Mission 41-E had already been cancelled.) This required returning the Space Shuttle to the VAB for disassembly and then the orbiter to the OPF for cargo bay reconfiguration. The main engine which had failed was also replaced.

Once in orbit Discovery experienced no further problems and the crew successfully performed all planned work. They deployed three large communications satellites, extended and tested the OAST-1 solar cell wing, operated the CFES system, took extensive footage with the several cameras aboard, and used the Canadarm to dislodge a block of ice that appeared around a water outlet opening.



On the STS 41-D mission engineer Charles D. Walker, a McDonnell Douglas employee, became the first representative from industry to train as a payload specialist and operate his company's equipment onboard the Space Shuttle.

At 9:37 a.m. EDT on September 5, 1984, Commander Henry Hartsfield landed Discovery on Runway 17 at Edwards AFB, after a mission duration of 6 days and 56 minutes.

Crew. The crew members were Henry W. Hartsfield, Jr., Commander; Michael L. Coats, Pilot; Judith A. Resnik, Steven A. Hawley and Richard M. Mullane, Mission Specialists; and Charles D. Walker, Payload Specialist. Walker, a McDonnell Douglas employee, became the first commercial Payload Specialist assigned by NASA to a Space Shuttle flight crew.

The SYNCOM IV-2 spacecraft, also called Leasat 2, spins slowly away from the orbiter after being deployed during the STS 41-D mission. This was the second of three successful deployments of commercial communications satellites for 41-D, and the first using a ride-spinning "frisbee" deployment system.

Payload and Experiments. The combined cargo of most major items from two prior planned missions weighed more than 47,000 pounds, the heaviest Space Shuttle payload to date. This included three communications satellites and their perigee motors. Two of these, SBS-D and Telstar 3-C, were Hughes HS 376 spacecraft with PAM-D motors attached. The third was SYNCOM IV-2, also known as LEASAT 2, a larger spacecraft built by Hughes that was specifically designed to be deployed from the Space Shuttle.

SBS-D was deployed about eight hours into the mission, SYNCOM IV-2 on the second day, and Telstar 3-C on the third day. The satellite owners/operators assumed control and responsibility once the spacecraft were clear of the orbiter. Both PAM-D motors fired properly and carried their spacecraft into the planned geosynchronous transfer orbits. SYNCOM IV-2, which had a Minuteman Missile third stage as a solid propellant perigee motor, had a gross weight of 17,049 pounds. When fired by automatic sequence this motor boosted the spacecraft into an elliptical orbit with an apogee of about 9,500 miles. A series of firings at perigee by two small liquid hydrazine-nitrogen tetroxide engines raised the apogee to the geosynchronous altitude of 22,300 miles, and further firings circularized the orbit over the equator. The two HS 376 spacecraft used small on-board solid rocket motors, firing at apogee, to accomplish this equatorial placement and orbital circularization. The owners/operators of the three spacecraft then began checkout operations.

Smaller payloads included the OAST-1 solar wing, which is 13 ft wide and extends to a height of 102 ft in space, but folds into a package only seven inches deep in its container. It featured small samples of several types of solar cells, which occupied only a fraction of the total space available. The wing was extended and refolded several times, as planned, and the orbiter's vernier engines were fired with the wing extended to determine the amount of movement and vibration under stress.

Payload Specialist Charles Walker operated the CFES in the middeck to produce a proprietary pharmaceutical product for McDonnell Douglas. Walker experienced some mechanical problems, but solved them and accomplished almost all of his planned work.

A Shuttle Student Involvement Project (SSIP) experiment on crystal growth in zero gravity was conducted. Footage using the IMAX large-film camera system was obtained throughout the mission. Other camera systems stowed in the middeck were used to photograph clouds in the atmosphere and strips of various spacecraft materials attached to the Canadarm.

STS 41-G Mission

The Orbiter Challenger lifted off from Pad A, Launch Complex 39, KSC, at 7:03 a.m. EDT on October 5, 1984. This was the sixth launch for the Challenger, and the thirteenth flight of the Space Shuttle. This mission included several firsts, among them the first flight with seven crew members, the first to fly two female astronauts (Ride and Sullivan), first flight by a Canadian astronaut (Garneau), first spacewalk by an American woman (Sullivan), first astronaut to fly a fourth Space Shuttle mission (Crippen), and the first demonstration of a refueling in orbit technique to illustrate how the useful life of some orbiting satellites can be greatly extended. One spacecraft, the Earth Radiation Budget Satellite (ERBS), was deployed on this scientifically oriented, primarily NASA mission.

Challenger landed at the Kennedy Space Center, with Commander Crippen at the controls. This was the second landing at the launch site in the STS program. The time was 12:26 p.m. EDT on October 13, after a mission duration of eight days, five hours and 23 minutes.

Crew. The crew members were Robert L. Crippen, Commander; Jon A. McBride, Pilot; Kathryn D. Sullivan, Sally

K. Ride and David C. Leestma, Mission Specialists; and Paul Scully-Power and Marc Garneau, Payload Specialists.

Payload and Experiments. The first major task in orbit was deploying the ERBS. The effort began less than nine hours into the mission, when the spacecraft was lifted out of the cargo bay by the Canadarm. The ERBS solar panels did not unfold properly, a problem assumed to be due to the cold. The crew held the ERBS in sunlight for several minutes, and the panels finally unfolded. It was then released by the Canadarm. ERBS later used its on-board thrusters to raise its orbit to the operational altitude of around 350 miles.

The second major activity was the activation of the Shuttle Imaging Radar-B (SIR-B) portion of the OSTA-3 package of experiments. The radar worked well, but a failure in the ability of the orbiter's Ku-band antenna left it unable to track. The crew had to lock this antenna in place, then maneuver the entire orbiter to keep the antenna pointed at the Tracking and Data Relay Satellite (TDRS). This required storing all SIR-B data on tape, eliminating "live" transmissions, and taking far more operating time. The quality of the radar images obtained was outstanding, but the antenna problem kept data acquisition to about 20% of what had been planned. After several days and the completion of SIR-B operations, its antenna refused to fold up on command. It had to be nudged closed with the Canadarm, a delicate operation that was completed without difficulty.

Astronaut Kathryn D. Sullivan checks the latch of the SIR-B antenna in the Challenger's open cargo bay during her historic extravehicular activity on October 11, 1984. The primarily scientific mission of STS 41-G was to deploy an Earth Radiation Budget Satellite and perform a series of Earth observation experiments.

The problems with the SIR-B delayed the planned spacewalks of Leestma and Sullivan by two days. Then, during 3-1/2 hours in the cargo bay, they connected the components of the Orbital Refueling System (ORS), which was later operated several times. This demonstrated that it is possible and practical to refuel satellites in orbit, including some spacecraft not originally designed to have their useful lives extended.

A series of Canadian experiments (CANEX), performed in the varied fields of medical, atmospheric, climatic, materials and robotic sciences, were performed by Canadian payload specialist Garneau. The second payload specialist, Scully-Power, working for the Naval Research Laboratory, performed a series of important observations in oceanography. The astronauts also performed three more OSTA-3 experiments, taking detailed photographs of the Earth using the Large Format Camera (LFC), operating the Measurement of Air Pollution (MAPS) aerial camera, and the two television and two Hasselblad cameras in the Feature Identification and Location (FILE) experiment. The latter was also operated at times by ground command. The astronauts turned on the several experiments in the "Getaway Special" canisters in the cargo bay when required.

In the orbiter cabin the crew operated the IMAX large-film camera for the third time, completing the planned in-space footage for the IMAX film "The Dream is Alive." They also operated the Radiation Monitoring Equipment and performed a Thermoluminescent Dosimeter experiment to measure cosmic radiation doses during space flight. The latter was developed by the Central Research Institute for Physics in Budapest, Hungary.

The ERBS is the first of three planned sets of orbiting instruments in the Earth Radiation Budget Experiment. Two more sets will fly on NOAA weather satellites later. ERBS weighs 5,087 pounds and has three major instruments. It was built by Ball Aerospace. ERBS, when deployed, is 15 ft wide, 12.5 ft high and 5.2 ft long. The overall goal of the program is to measure the amount of energy received from the Sun and reradiated into space, and the seasonal movement of energy from the tropics to the poles.

The OSTA-3 components consisted of the SIR-B, the LFC, the MAPS, and the FILE. The SIR-A instrument on STS-2 achieved spectacular results. The improved SIR-B has an antenna consisting of a 35-by-7 ft array of eight panels. (SIR-A had seven panels.) The new antenna also tilts from 15 to 60 degrees, allowing the viewing of targets from several angles during successive orbital passes. The LFC, making its first flight, has a unique lens that combines high resolution and a wide field of view for precise stereo photography. It can resolve objects as small as 70 ft long, the length of a normal house. A single frame can photograph an area larger than the state of Massachusetts. The MAPS instrument measures the distribution of industrial wastes, such as carbon monoxide, in the troposhere over the entire globe. It consists of an aerial camera and supporting equipment. FILE is designed to help develop equipment which will make remote sensing instruments more efficient. It has two specialized television cameras, two Hasselblad 70mm cameras, and supporting equipment.

The Canadian experiment set (CANEX) consists of medical, atmospheric, materials science and robotics experiments, largely performed by Garneau, with himself as the primary medical subject.

The ORS experiment required space-suited astronauts working in the cargo bay to attach a hydrazine servicing tool, already connected to a portable fuel tank, to a simulated

satellite panel. After leak checks the astronauts returned to the orbiter cabin and the actual movement of hydrazine from tank to tank was controlled from the flight deck.

The "Getaway Special" experiments covered a wide variety of work in materials testing and physics.

STS 51-A Mission

The Orbiter Discovery lifted off from Pad A, Launch Complex 39, KSC, at 7:15 a.m. EST on November 8, 1984. This was the second launch of Discovery, and the fourteenth launch of the Space Shuttle vehicle. The launch had been delayed one day by high-altitude "shear winds," a first in the Shuttle program.

STS 51-A had two primary objectives, to deploy the Anik D2 and SYNCOM IV-1 (LEASAT 1) communications spacecraft, and recover and return to Earth the two satellites placed in improper orbits by faulty perigee motors on STS 41-B. This recovery was the third and last segment of a three-part effort to demonstrate a new capability in the space program, the repair and/or recovery of malfunctioning satellites. The first segment was the repair in orbit of the Solar Maximum Mission satellite on STS 41-C, and the second was a demonstration of the ability to refuel satellites in orbit performed on STS 41-G.

Commander Hauck landed Discovery at the Kennedy Space Center on November 16, at 7:00 a.m. EST, after a mission duration of seven days, 23 hours and 45 minutes.

Crew. The crew members were Frederick H. Hauck, Commander; David M. Walker, Pilot; and Joseph P. Allen, Anna L. Fisher and Dale A. Gardner, Mission Specialists. It was the first space mission for Walker and Fisher.

Payload and Experiments. The Anik D2 was deployed on the second day of the mission, and SYNCOM IV-1 on the third day. The orbiter then began a long series of burns needed to rendezvous with the first of the two satellites to be recovered, PALAPA B-2. Both had been lowered from their original altitudes of over 600 miles to about 210 miles to facilitate recovery. PALAPA B-2 was recovered on the fifth day, and WESTAR VI on the sixth. The usual radiation monitoring experiment was performed in the crew areas, and one major experiment, the Diffusive Mixing of Organic Solutions (DMOS), the first of over 70 organic and polymer science experiments being conducted by 3M, was successfully completed.

The ANIK D2 spacecraft, built by Spar Aerospace of Canada, with Hughes Aircraft as a major subcontractor, is very similar to the Hughes HS 376 series of communications satellites. It utilizes the PAM-D motor as a perigee stage. The SYNCOM IV-1 is a twin to SYNCOM IV-2, launched earlier on the STS 41-D mission. Each spacecraft perigee motor fired on time about 45 minutes after deployment, and both spacecraft entered the planned elliptical geosynchronous transfer orbits. A later firing of the on-board solid propellant apogee motor on ANIK D-2 circularized its orbit over the equator. The Minuteman III third stage utilized by SYNCOM IV-2 as a perigee motor carried it about halfway to altitude as planned, after which a series of firings by its hydrazine-nitrogen tetroxide thrusters raised it to the geosynchronous altitude of 22,300 miles and circularized its orbit over the equator. Both entered checkout procedures by Hughes and/or the owners in preparation for active service.

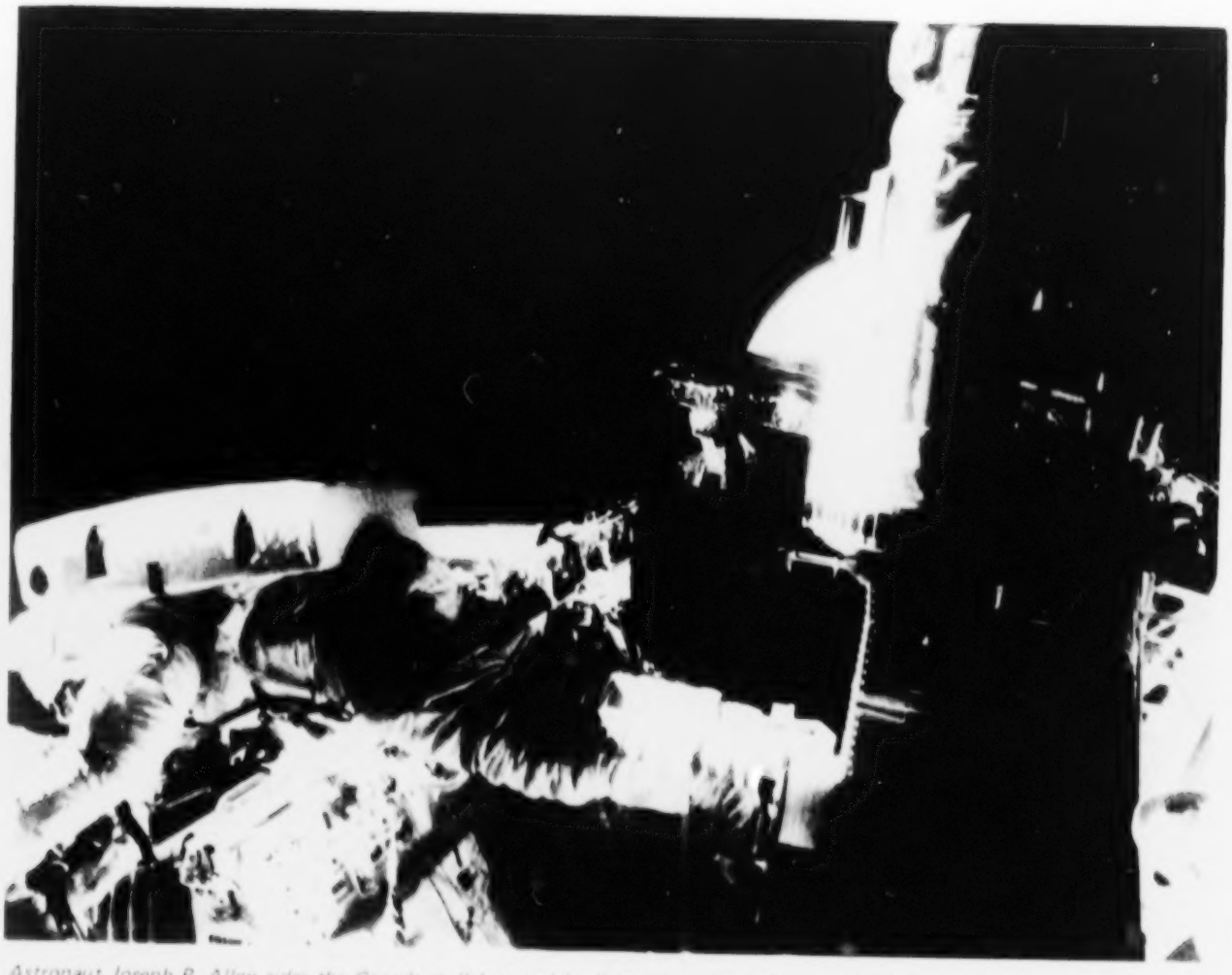
Astronaut Dale A. Gardner left, holds a "for sale" sign to indicate he and astronaut Joseph P. Allen have just successfully captured and anchored the errant WESTAR VI satellite. Allen is riding the Mobile Foot Restraint held by the Canadarm, operated by Anna Fisher from inside the orbiter.

The second major mission objective was the recovery of the PALAPA B-2 and WESTAR VI satellites. Two empty cradles similar to or identical with those from which the two satellites had originally been deployed were part of the STS 51-A cargo. After rendezvous was achieved with PALAPA B-2 on the fifth day, Allen and Gardner went EVA to capture the satellite. A device called a "Stinger" was inserted into the apogee motor nozzle by Allen, locking the satellite to his MMU. The MMU jets then stopped the one rpm rotation. After Allen disengaged himself and left the Stinger in place, Fisher operated the Canadarm to grasp the satellite by a special attachment on the Stinger and bring it into the cargo bay. The omni antenna was removed and Gardner attempted to install a bridge structure across the top of the satellite, one with a special attach fitting that would have made it possible for Fisher to grasp it with the Canadarm. The bridge structure did not fit, making it impossible to use the Canadarm, and Allen had to manually steady the spacecraft for two hours while Gardner prepared it for berthing. It was eventually pulled down into its cradle largely by

muscle power. The two astronauts, working in the microgravity of orbit, managed to move the mass of the satellite as necessary to dock and secure it in its cradle.

The WESTAR VI satellite was in an orbit very close to that of PALAPA B 2, but about 700 miles ahead. After one more day of maneuvering Discovery caught up with it, and Allen and Gardner exchanged work assignments and captured it also. This time they did not attempt to use the bridge, but followed the same muscle powered procedures that had worked for PALAPA B 2.

The astronauts in the crew compartment operated the DMOS equipment in the mid-deck during the mission. The chemical mixes that resulted were turned over to 3M for analysis. The radiation monitoring which is a standard feature of STS flights was performed as usual.



Astronaut Joseph P. Allen rides the Canadarm "cherry picker" attachment while suspended horizontally above the cargo bay. The spacecraft behind him is the Westar VI, which the crew had just captured and locked into the cargo bay on the STS 51-A mission.

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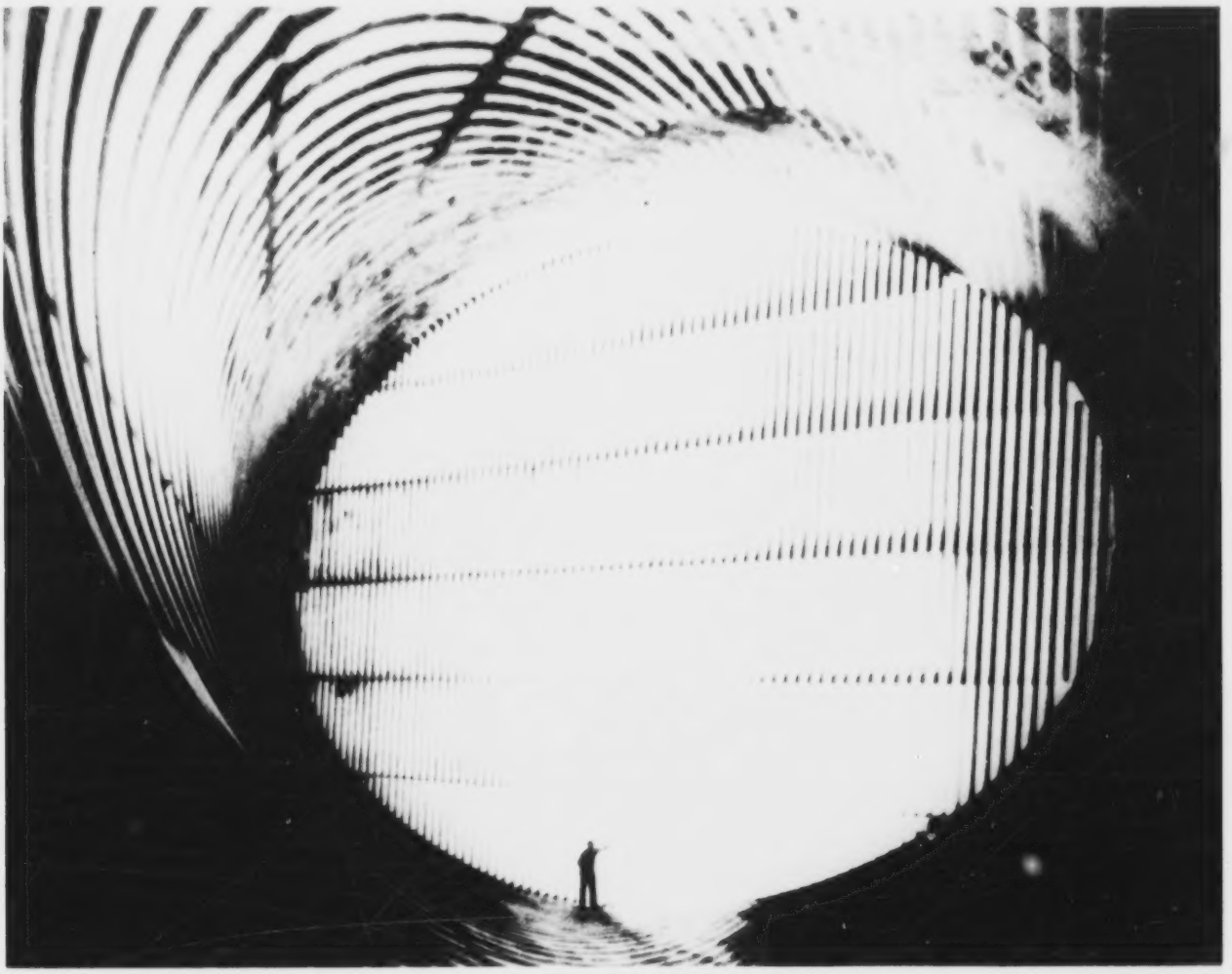
Information Summaries

PMS 002 (LaRC)

May 1988

NASA's Wind Tunnels



Giant vanes help the airflow around a corner in this transonic wind tunnel at NASA's Langley Research Center.

How Wind Tunnels Work

Wind tunnels are machines for "flying" aircraft on the ground. Wind tunnels are tubelike structures or passages in which wind is produced, usually by a large fan, to flow over objects such as aircraft, engines, wings, rockets or models of these objects. A stationary object is placed in the test section of a tunnel and connected to instruments that measure and record airflow around the object and the aerodynamic forces that act upon it. From information gathered in these observations, engineers can determine the behavior of an aircraft or its components at takeoff, while cruising, and during descent and landing.

Wind tunnels also help engineers determine the performance of, and eliminate "bugs" in, new designs of civil and military aircraft without risk to a pilot or costly aircraft. Responses to flight conditions of new materials and shapes for wings, ailerons, tails, fuselages, landing gear, power systems and engine cowlings can be assessed before these designs are incorporated into aircraft.

Today, no aircraft, spacecraft or space launch or reentry vehicle is built or committed to flight until after its design and components have been thoroughly tested in wind tunnels. Every modern aircraft and space rocket has made its maiden flight in a wind tunnel. Wind tunnels have been among the key tools which have made American aircraft and aeronautical equipment the most desired and most widely used in the world.

The National Aeronautics and Space Administration maintains the largest number and variety of wind tunnels ever operated by any single agency or company. NASA's 42 major wind tunnels vary in size from those large enough to test a full-sized airplane to those with a test section only a few inches square where models as small as a match are tested.

Types of Wind Tunnels

According to NASA's official "Aeronautical Facilities Catalogue," which lists prime installations, 23 major wind tunnels are at the Langley Research Center in Hampton, Virginia, and 12 are at the Ames Research Center in Mountain View, California. Six others are at the Lewis Research Center in Cleveland, Ohio, and one is at the Marshall Space Flight Center in Huntsville, Alabama.

Some of these tunnels are designed for the study of wing and fuselage shapes. Other wind tunnels are devoted either to testing propulsion systems or are designed for tests at various speeds. Air flow in a wind tunnel is produced and conditioned in several ways to simulate flight at the speeds, altitudes and temperatures that would be encountered by particular kinds of aircraft. The speed of air flowing through a tunnel is usually expressed in terms of the speed of sound (760 mph at sea level). The ratio between the speed of air flow and the speed of sound is called a Mach number. At Mach 2, for example, the speed of a vehicle is twice the speed of sound, or 1,520 mph at sea level.

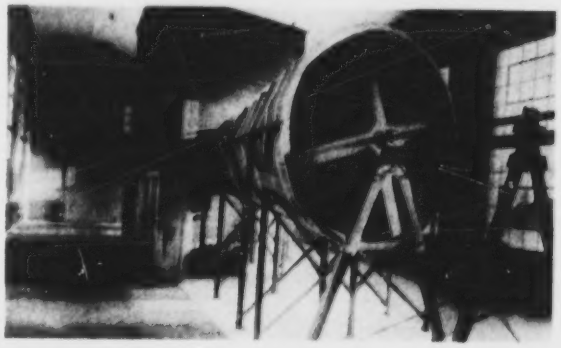
Some tunnels specialize in accelerating air only to *subsonic* speeds which are slower than the speed of sound. Others reach *transonic* air speeds (slightly below, through and above the speed of sound), *supersonic* speeds (much faster than sound), and *hypersonic* speeds (more than five times the speed of sound).

High wind speeds are needed for testing proposed components for advanced research aircraft, such as the envisioned U.S. National Aero-Space Plane. This experimental aircraft, which is expected to make its first test flights in the mid-1990s, may lead to an airplane-like orbital launch vehicle. It may also lead to passenger vehicles able to fly through the highest reaches of the Earth's atmosphere and take passengers anywhere on Earth in 4 hours or less.

Some of NASA's wind tunnels are equipped with lasers for a technique called laser doppler velocimetry. This is one of several new non-intrusive techniques which make possible precise determination of velocities with light beams. The light beams do not interfere with the airflow, as happens with measuring instruments that require a physical presence in the test chamber.

A Brief History

Like aircraft, wind tunnels have come a long way in their technological development. Their sophistication has kept pace with the needs of designers. The first major U.S. Government wind tunnel was built at NASA's Langley Research Center and became operational in 1921. The Center was the first major research facility of the U.S. National Advisory Committee for Aeronautics (NACA), which was founded in 1915. NACA later became a part of NASA when it was established on October 1, 1958, to carry out space research and exploration and to continue NACA's aeronautical work.



The first major U.S. wind tunnel was built at NASA's Langley Research Center, Hampton, Virginia, in 1920.

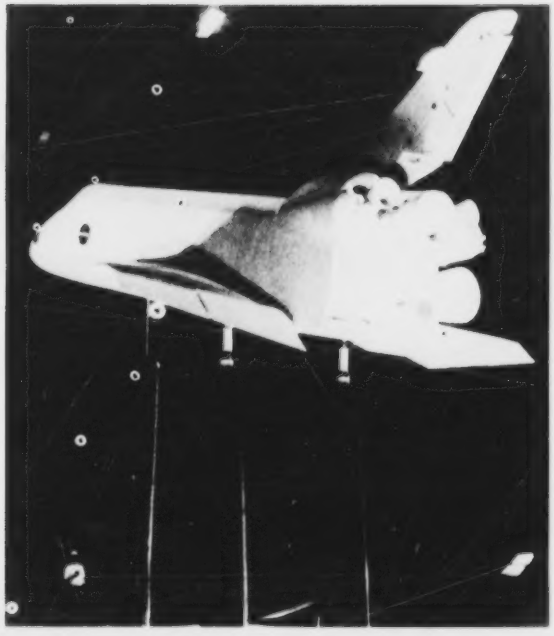
Late in the last century, however, the first wind tunnels were little more than boxes or pipes. A fan or other device propelled air over a model of an aircraft or of a wing suspended in the pipe or box. Observation instruments were crude. The researchers had to gather many of the test results with their own eyes. The Wright brothers designed and used such primitive tunnels to develop the wing configurations and control surfaces with which they achieved the first powered human flight early in this century.

Early theorists became aware that an aircraft's shape, construction, and materials significantly influence its ability to climb and carry loads. Researchers discovered that subtle variations in the shape of wings and of the contours of other surfaces can cause dramatic changes in air resistance. This affects speed, fuel economy and other flight characteristics, such as maneuverability and load capacity.

Early researchers also discovered that tests with scale models often did not match the experience of flight with a full-scale aircraft. The researchers found that one way to bring research results closer to flight experience with a one-fifth scale model, for instance, was to test the model under a pressure of five atmospheres. The researchers recommended testing small-scale models at very high pressures to properly simulate full-scale flight conditions.

In wind tunnels at NASA's Ames and Langley Research Centers, crucial reentry tests were performed in the 1970s

with the U.S. Space Shuttle. These tests simulated the severe heating from atmospheric friction that the space transportation system later had to withstand during its flights in the 1980s. Simulations also have been conducted to study the entry problems expected to be encountered by unmanned planetary craft intended for passage through the extreme temperatures and unusual atmospheric gases of Venus, Jupiter and other solar system bodies.



Scale model of the Shuttle Orbiter inside the 40- by 80-foot test section of a wind tunnel at NASA's Ames Research Center. Instrumented supports provide data on the model's aerodynamic characteristics.

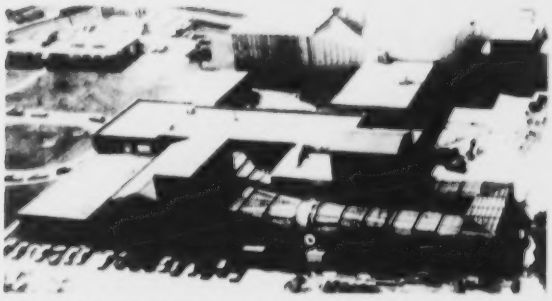
Today's aircraft are larger, cruise faster and higher, carry more passengers and cargo, and use less fuel per mile than most of their predecessors. Aircraft now being developed are expected to show significant improvements in all of these performance characteristics.

Current Wind Tunnels

The world's first high-pressure tunnel, the "Variable Density Tunnel," began operations at Langley Research Center in March 1923. That tunnel's importance was emphasized again in 1986, when it was designated as a National Historic Landmark by the U.S. Department of the Interior.

Through the years, tests carried out in this tunnel achieved technological quantum leaps. One of its most famous contributions was research that culminated in a document which became globally known among aeronautical engineers and designers as Technical Report 460.

That report provided data on lift and drag for 78 different shapes of wings and other airfoils. These data eventually found their way into designs of some of history's most successful aircraft, including the DC-3 transports and the B-17 Flying Fortresses of World War II. These early experiments were among numerous landmark accomplishments which have made the Langley Research Center an almost legendary institution in aircraft development. Langley is also the site of the world's first transonic wind tunnel.



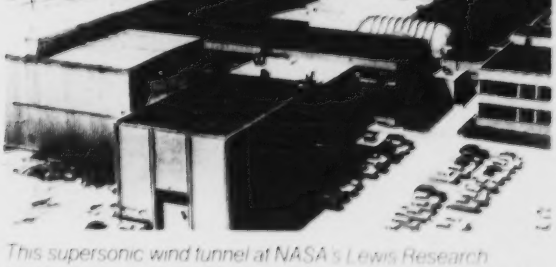
This wind tunnel, which has a 7- by 10-foot test section, is one of 23 major wind tunnels at NASA's Langley Research Center, Hampton, Virginia.

One of Langley Research Center's most advanced facilities is the National Transonic Facility (NTF), which completed its first year of operation in 1984. In the NTF, super cold liquid nitrogen is injected, which evaporates into gas that is accelerated through the tunnel's test section at speeds up to 1.2 times the speed of sound. The low temperatures increase the density and decrease the viscosity of the atmosphere and, thus, simulate with great accuracy full-scale flight conditions at transonic speeds.

A wind tunnel is often identified by the size of its test section, as opposed to overall size of the tunnel. Test sections are the chambers in which aircraft models or other objects are tested. In a 13-inch research tunnel at Langley Research Center, experiments are underway using "magnetic suspension." Models are held in position with powerful magnets to eliminate the need for physical mounting mechanisms which interfere with the airflow or alter the model's geometry.

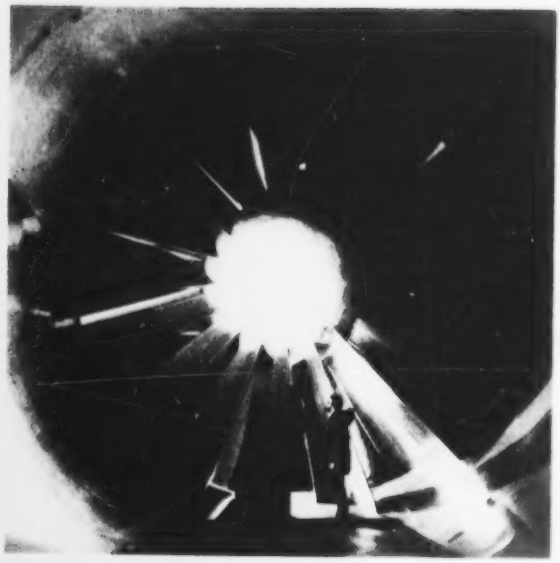
NASA's Lewis Research Center is known for its studies and innovations in aircraft propulsion systems. One of its wind tunnels, built in the 1950s, has a 10- by 10-foot test section in which aircraft models can be examined while their engines are running. In such tests, new air is continuously drawn into the tunnel and is then expelled after passing through the tunnel only once. The tunnel can also be operated in a mode like most other wind tunnels which circulate the same air repeatedly through their loops. In this way, a tunnel can better maintain high atmospheric pressure, desired temperatures or moisture content in its test section.

The 8- by 6-foot propulsion research tunnel at Lewis can push 150,000 pounds of air every minute across the test section at up to twice the speed of sound. In 1968, a 9- by 15-foot subsonic test section was added to that tunnel for research on surfaces and power plants of V/STOL (vertical and short-takeoff-and-landing) aircraft.



This supersonic wind tunnel at NASA's Lewis Research Center can push 150,000 pounds of air each minute at twice the speed of sound past models in its 8- by 6-foot test section located in the dome in the center of this photo.

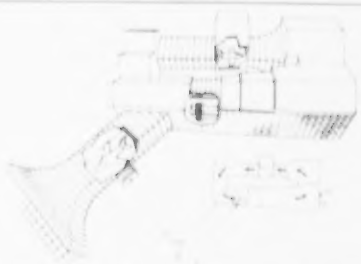
The Lewis Research Center's 6- by 9- by 20-foot Icing Research Tunnel, built in 1944, is the world's largest refrigerated tunnel for year-round use for examining protection systems against hazardous ice formations on wings, air inlets, rotors and V/STOL aircraft.



Ice on wings and other aircraft surfaces has been a major cause of accidents. These stationary blades help control airflow inside the Icing Research Tunnel at NASA's Lewis Research Center. Engineers experiment with ways of preventing ice buildup and better predicting its formation. Results of tests such as this will be presented in London.

The largest wind tunnel in the free world is at NASA's Ames Research Center. The massive facility, which can test planes with wingspans of up to 120 feet at more than 1,400 feet long and 180 feet high, has two test sections: one 80 feet high and 120 feet wide, the other 40 feet high and 80 feet wide. Air is driven through these test sections by six 15-bladed fans. Each fan has a diameter equal to the height of a four-story building. The fans are powered by six 22,500-horsepower motors.

The free world's largest wind tunnel is housed in this huge multi-roofed building at the NASA Ames Research Center, Mountain View, California. One of the tunnel's air intakes is in the foreground (top right). The pipe-like structures (lower left) are high-pressure wind tunnels.



Diagrams depict the wind tunnel shown in the lower left photo. Cutaways in upper diagram show airplanes or models being tested and the fans which provide the airflow. Black arrows in the smaller diagram show circular airflow for the (upper) 40- by 80-foot test chamber. White arrows depict the one-way airflow from the horn through the 80- by 120-foot test chamber and to outside.

The Ames and Langley Research Centers each have a "Unitary Plan Facility." The Ames facility opened in 1956, with three test sections—a transonic section that is 11 feet wide and 11 feet high, and two subsonic sections that measure 9 feet by 7 and 8 feet by 7 feet. In these sections the air can be adjusted to simulate flying conditions at various altitudes.

Something new is being attempted at the Ames Center with a 35-year-old, "2- by 2-foot" wind tunnel which is being modernized with the installation of computer-controlled walls. These walls automatically add or expel air from the tunnel ducts. This lessens interference on the airflow by the walls. Thus, this wind tunnel can more realistically simulate conditions of an aircraft in the open, wall-free natural flight environment.

Similar advantages are being pursued at the Lewis and Langley Centers, where engineers are experimenting with various kinds of "adaptive walls" or "smart walls." These expand and contract in ingenious ways to virtually remove the distorting effects walls can have on a tunnel's airflow. Such adaptive walls are among the newest innovations in wind tunnel technology.

George C. Marshall Space Flight Center's 14- by 14-inch Trisonic Wind Facility got its name because it can conduct tests in three speed regimes from subsonic through transonic to supersonic, from ½ to 2½ times the speed of sound. Similarly, the Center's High Reynolds Number Wind Tunnel can produce wind speeds ranging from ¼ to 3½ times the speed of sound in simulations that give results very closely resembling those of actual flight experience.

The Department of Defense operates several major wind tunnels, as do some U.S. industries and universities. Nations which have major wind tunnels listed in NASA's "Aeronautical Facilities Catalogue" include the United Kingdom, 27; France, 18; Japan, 16; West Germany, 11; the Netherlands, 4; and Canada, 5. Unknown publicly is the number and kinds of wind tunnels in the Soviet Union, in other East European countries, or in the People's Republic of China.

NASA's wind tunnels are a national technological resource. They have provided vast knowledge that has contributed to the development and advancement of the nation's aviation industry, space program, economy and the national security. Amid today's increasingly fierce international, commercial and technological competition, NASA's wind tunnels are crucial tools for helping the United States retain its global leadership in aviation and space flight.

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